Phytoremediation of Wastewater through Implemented Wetland – A Review

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Abstract. Contrary to the typical treatment system, built wetland systems have become high-performance wastewater treatment technology in recent years. In India as well, this technology is becoming more important for reducing water pollution. A built wetland is essentially a tank that has been planted with plants tolerant of waterlogged conditions and filled with a substrate. In this method, wastewater is treated by plants through phytoremediation. A manmade wetland's plant species is crucial in maintaining the temperature needed for a variety of biological and physiological processes necessary for the efficient treatment of wastewater. Hydraulic retention time (HRT), plant type, and bed material make up a built wetland's key elements. Generally, gravels and sand are used as the bed media and the plant species used are grasses like typha grass, canna indica, para grass, etc. Environmental-related parameters that are taken into consideration are pH, COD, BOD, TSS, NH_3-N, PO_4, nitrate, and Fecal coliform count in one complete macrophyte life cycle. The present paper gives information about the different types of constructed wetlands, pollutants removal mechanism by microphytes, engineering design used, and application of implemented wetlands.

Keywords: Implemented wetland, wastewater, microphytes, pollutant removal, etc.

1. Introduction

Wastewater poses the greatest hazard to the area where untreated water is discharged often, which makes it difficult to manage the difficulties in providing clean water to rural and urban areas [1]. The effluents promote eutrophication and water contamination, and they are the main culprits. However, this could promote the growth of algae, increase the expense of water purification, endanger humans and cattle, and result in excessive oxygen loss, all of which could result in a variety of alterations to the aquatic system's population [2,3,4]. In the age of industrialism, mankind released a large number of dangerous chemical and non-chemical substances into the environment. Pollutants can seriously endanger human health, and they include dyes, heavy metals, and toxic organic and inorganic substances. To avoid, eliminate, and remedy the detrimental effects of pollutants emitted into the environment, a variety of strategies and methods may be employed. It is possible to apply a practical, affordable strategy to lessen the danger that contaminated areas would harm the ecosystem and people's health [5,6,7]. By preventing light from penetrating, toxic substances have a negative effect on the water environment by preventing aquatic plants from photosynthesizing [8]. Numerous techniques, including membrane filtration, reverse osmosis, chemical precipitation, oxidation, adsorption, and flotation, might lessen the impact of hazardous metal ions. However, due to the reception of metal in low concentrations, which has practical economic properties, adsorption is very precise and common. [9,10]. The purpose of the current research is to explain Wastewater Phytoremediation Using a Wetland Implementation.

A wetland is an environment that experiences seasonal or persistent flooding with water and supports oxygen-free processes. The aquatic plants, which have been adapted to the particular hydric soil, are the primary characteristic that sets wetlands apart from other landforms or bodies of water. In addition to purifying and storing water, wetlands also recycle carbon and other nutrients, stabilize shorelines, and support a variety of plant and animal species. Wetlands are among the environments with the greatest biological diversity; they provide a home for a vast variety of plant and animal species. In many areas, methods for quickly evaluating these activities, wetland ecological health, and overall wetland condition have been established. These methods have helped to preserve wetlands by, among other things, increasing public awareness of the ecosystem services that some wetlands offer. Wetlands may include freshwater or wastewater [11-14].

1.1 Implemented Wetland

Implemented wetlands (IW) are man-made ecosystems that were intentionally developed to treat wastewater by leveraging microbial communities, vegetation, and soil-based natural processes. Kathe Seidel introduced the idea of artificial wetlands in the early 1950s. The initial Seidel systems, known as hydro botanical systems [15–19], consisted of a few sand and gravel beds with emergent vegetation.

1.2 Implemented Wetland Types

The following criteria can be used to categorize the various design configurations of implemented wetlands [37]

- The predominant macrophytes' life form (free-floating, emergent, submerged),
- The wetland systems' flow patterns (free water surface flow; subsurface flow that is both horizontal and vertical);
- The wetland cells' configurations (hybrid, one-stage, or multi-stage systems);
- The kind of wastewater that will be treated,
- The degree of wastewater treatment (basic or advanced),
- Pretreatment type,
- wastewater and effluent structures,
- substrate type (gravel, dirt, sand, etc.), and
- loading type (continuous or intermittent loading).

Only the subsurface flow implemented wetlands have been taken into account of the several classes stated above. In these wetlands, there are primarily two different sorts of flow directions. These are vertical flow (VF) and horizontal flow (HF) (VF).

1.2.1 Horizontal flow (HF)

It is known as an HF wetland because wastewater is fed in at the inlet and slowly moves in a more or less horizontal channel through the porous substrate beneath the surface of the bed until it reaches the outlet zone. A network of aerobic, anoxic, and anaerobic zones will come into touch with the wastewater throughout this journey. The aerobic zones will be located close to the wetland vegetation's roots and rhizomes where they release oxygen into the substrate. Wastewater is cleansed by microbial degradation as well as physical and chemical processes as it travels through the rhizosphere [38]. TSS, BOD_5, and COD can all be successfully removed from wastewater using HF wetland.

1.2.2 Vertical flow (VF)

A sand/gravel bed that has been covered in plant and vertical flow (VF) features a flat top. A drainage system at the bottom collects the wastewater when it progressively percolates through the bed after being fed from the top. Large batches of water are intermittently fed into VF wetlands to flood the surface. The liquid eventually percolates through the bed and is collected at the base by a drainage system. The bed drains entirely free of obstructions, allowing air to refresh the bed. The subsequent liquid dose traps this air, and this, together with the aeration brought on by the quick dosing onto the bed, results in good oxygen transfer and, consequently, the capacity to nitrify. In comparison to oxygen transfer through plants, the intermittent dosing system's air oxygen diffusion has a far greater impact on the oxygenation of the filter bed [39] demonstrated that oxygen transfer through plants (common reed species) has a potential oxygen transfer of 2 g O2.m-2. d-1 to the root zone, which is primarily utilized by the roots and rhizomes themselves.

1.2. 3 Hybrid flow

Due to its low oxygen transfer capacity, hybrid HF wetland is approved well for removing BOD5 and TSS for secondary wastewater treatment, but not for nitrification. Because VF wetland require significantly less space and have a much higher potential for oxygen transfer than HF, there has been an increase in interest in these areas. However, VF wetlands also have significant limitations, such as a lower solids removal efficiency and the potential to clog if the wrong media is chosen. These factors have led to an increase in interest in combination (hybrid) wetlands. The benefits and drawbacks of the HF and VF can be blended in these systems to balance one another out. HF wetland followed by VF wetland or VF wetland followed by HF wetland could be hybrid wetlands, depending on the intended use.

The following characteristics, as shown in Figure 1, can be used to design and categorize the created wetland [20–26].

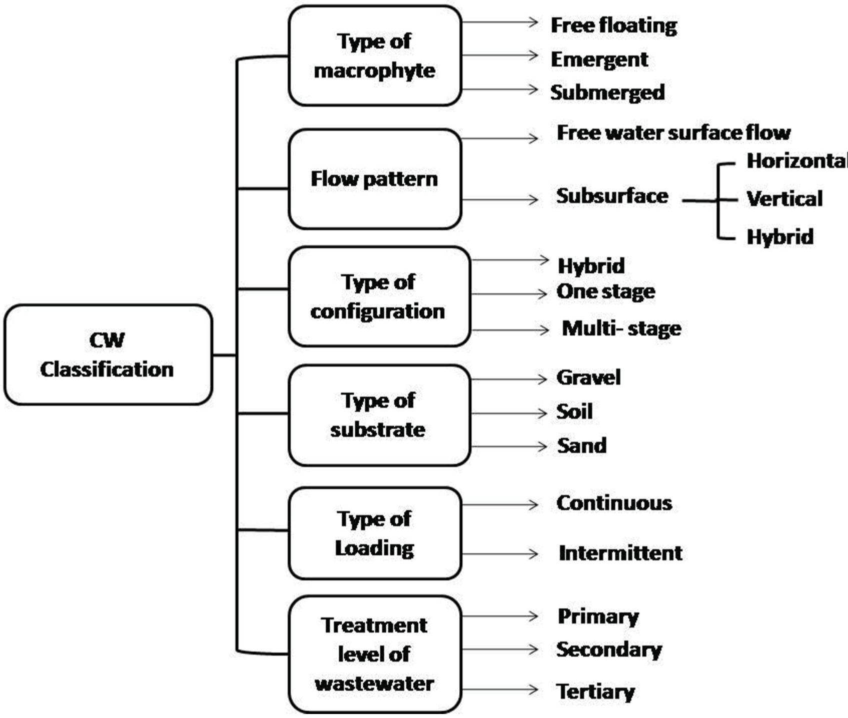

Fig.1. Implemented Wetland Types

1.3 Size of the Implemented Wetland

The Kickuth equation (Ah = Qd (ln Ci – ln Ce)/KBOD) is be used to determine the size of the wetland depending on the average daily sewage flow rate (m^3/d), bed surface area (m^2), both the influent and effluent BOD5 concentrations are given in mg/l and Rate constant (m/d) = KBOD

KBOD is dependent on the system's operational temperature (°C), the water column's depth (m), and the substrate medium's porosity (percentage expressed as fraction) Temperature affects KBOD, and generally, the rate of BOD decomposition rises by 10% each °C. We anticipate that the response rate constant for BOD degradation will be larger in the summer than in the winter. Additionally, it has been stated that as a system gets older, the KBOD rises.

1.4 Microphytes Used

Wetland plants, also known as macrophytes, are evolved to flourish in soils that are heavily soaked by water. According to the dominant macrophyte's life form, constructed wetlands for wastewater treatment can be divided into systems with free-floating, rooted emergent, and submerged macrophytes. The macrophytes have a significant role in the treatment of wastewater through the transfer of gases, the release of oxygen from the roots, the influence on the hydraulic conductivity of the soil, the intake of nutrients, and other processes. Additionally, the macrophytes offer more surface area for associated microbial development. The macrophytes also provide a secondary purpose that is unrelated to the treatment of wastewater but may be important in particular locations. The wetland vegetation may support a variety of animals, including birds, reptiles, and other creatures, in a huge system. It is possible to make sewage water treatment aesthetically beautiful by choosing attractive wetland plants, such as the yellow flag (Iris pseudacorus) or canna-likes [26-29].

2 Phytoremediation Process

The root zone, also known as the rhizosphere, is the active reaction zone in artificial wetlands (Fig. 2). The interplay of plants, microbes, the soil, and contaminants causes the physicochemical and biological processes that occur in this zone. The endorhizosphere, which refers to the interior of the root, and the ectorhizosphere, which refers to the root's surroundings, are two subtypes of rhizosphere. The rhizoplane is the region where these two areas converge. Here, it is anticipated that the plant and microbes will interact most actively [15,20 & 21].

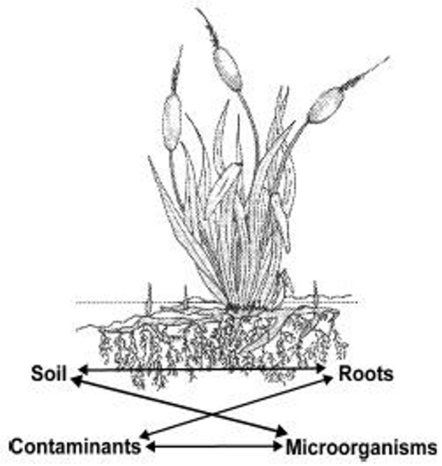

Fig. 2. Potential interaction in the wetland's root zone during wastewater treatment

Biological oxygen demand (BOD), suspended solids (SS), nitrogen, metals, and harmful microbes can all be greatly reduced by constructed wetlands. Aerobic bacteria linked to the media and the roots of the plants reduce BOD in wetlands. Natural re-aeration and plant roots both supply oxygen. In wetlands, nitrogen is altered through a number of processes, including ammonification, nitrification, denitrification, volatilization, adsorption, and bacterial and plant uptake. Fig. 3 depicts how these transformations interact with one another.

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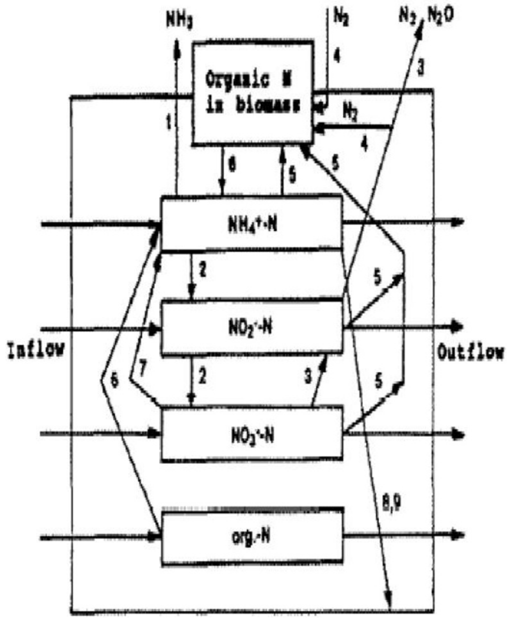

Fig. 3. Nitrogen Transformation in constructed wetland treating sewage water.

NH3-N volatilization, nitrification, denitrification, nitrogen fixation, plant, and microbial uptake are the first five processes. Sixth: Ammonization; seventh: Nitrate ammonification; eighth: Adsorption; and ninth: Ion exchange.

As the primary source of oxygen for the subsurface environment, the direct air oxygen penetration from the upper layer into the bed is typically minimal, which could jeopardize aerobic microbiological removal processes including respiration and nitrification. In order to induce aeration and raise the DO level in a sub-surface horizontal flow-built wetland so that the effluent can be released into rivers and agricultural fields [17 & 25], a compressor can be used.

3. Pollution Removal System

The created wetland's pollution-removal systems can be tabulated as in Table 1.

Table 1. Major pollutants and their removal mechanisms [8, 9, 22, 23, 24-39]

Pollutant	Main removal mechanism
Suspended solids	• Filtration • Sedimentation
Nitrogen	• Ammonia volatilization (primarily in SF system), • Ammonification accompanied by nitrification and denitrification; • Plant uptake (with only minor influence); and • Export through biomass harvesting.
Phosphorous	• The soil's retention through adsorption and precipitation reactions made possible by filter media • Calcium, aluminium, and iron-containing precipitation • Plant uptake
Pathogens	• Sedimentation, • filtering, • UV radiation, • natural die-off as a result of the prolonged retention time, • predatory activity (protozoa and metazoa), • as well as natural die-off (SF system)
Heavy metals	• Precipitation and adsorption • Plant uptake (partial) • Cation exchange • Complexation • Microbial Oxidation /reduction
Organic contaminants	• Filtration or settling (Particulate organic matter). • Microbial degradation caused by aerobic and anaerobic bacteria (Soluble organic matter) • Clay particle adsorption and microbial adsorption • Decomposition brought on by soil microorganisms that are both aerobic and anaerobic and by prolonged holding

During the above processes, the expected COD and BOD removal is up to 80%, suspended solids up to 90%, NH_3-N up to 75%, PO_4 up to 75%, nitrate up to 80%, and Fecal coliform count up to nearly 3 log reduction.

Advantages of Implemented Wetlands

- Construction of implemented wetlands is a less expensive than alternative remediation solutions,
- Uses organic processes,
- Simple operation and maintenance;
- Simple construction (may be constructed with local materials);
- Process stability.

Restrictions on implemented wetlands

- Need for a big area

- Design requirements have not yet been created for various types of wastewater and climates,
- Wetland treatment may only be cost-effective compared to alternative choices in areas where land is accessible and affordable.

Bio-magnified pollutants can have a significant impact on aquatic ecosystems, including Integrated Water (IW) systems. The fate of these pollutants in IW systems depends on various factors such as the specific pollutants involved, the characteristics of the system, and the treatment processes in place. However, information can be provided with some general information on the potential fate of bio-magnified pollutants in IW systems such as:
Accumulation in aquatic organisms: Bio-magnified pollutants, such as certain heavy metals or persistent organic pollutants, tend to accumulate in the tissues of aquatic organisms through the food chain. This accumulation can lead to toxic effects on the organisms themselves, as well as pose risks to organisms higher up the food chain, including humans if they consume contaminated seafood.
Impact on water quality: When bio-magnified pollutants enter IW systems, they can affect water quality. They may alter the chemical composition of the water, making it unsuitable for various uses such as drinking water or irrigation. High levels of pollutants can also lead to the eutrophication of water bodies, causing algal blooms and disrupting the balance of the ecosystem.
Removal during treatment processes: Many IW systems include treatment processes to remove pollutants from the water. Depending on the nature of the pollutants, various treatment techniques such as filtration, sedimentation, coagulation, and disinfection can be employed. However, some bio-magnified pollutants may be challenging to remove completely, especially if they are persistent or have complex chemical properties.
Environmental persistence: Certain bio-magnified pollutants are persistent in the environment, meaning they do not easily break down or degrade over time. These pollutants can persist in IW systems, potentially leading to long-term contamination. This persistence may require more advanced treatment techniques or additional measures to mitigate their impacts effectively. It's important to note that the fate of bio-magnified pollutants in IW systems can vary depending on local conditions, the specific pollutants involved, and the effectiveness of water management and treatment practices in place. Monitoring, regulation, and the implementation of appropriate treatment technologies are key to minimizing the impact of these pollutants on aquatic ecosystems and human health.

4. Conclusion

Constructed wetland systems are high-performance wastewater treatment method that is less expensive than conventional treatment systems. Based on the amount of pollutants in the wastewater, the climate, the kind of plants, and the amount of upkeep required for the wetland, the type of wetland can be determined.

References

1. Rashidi, H., Ghaffarian Hoseini, A., Ghaffarian Hoseini, A., Sulaiman, N. M. N., Tookey, J., & Hashim, N. A. (2015). Application of wastewater treatment in sustainable design of green built environments: A review. Renewable and Sustainable Energy Reviews, **49**, 845-856.
2. Akpor, O. B., & Muchie, B. (2011). Environmental and public health implications of wastewater quality. African Journal of Biotechnology, **10(13)**, 2379-2387.

3. Zhang, S., Wang, J., Zhang, Y., Ma, J., Huang, L., Yu, S. & Wang, X. (2021). Applications of water-stable metal-organic frameworks in the removal of water pollutants: A review. Environmental Pollution, **291**, 118076.
4. Zamel, D., Hassanin, A. H., Ellethy, R., Singer, G., & Abdelmoneim, A. (2019). Novel bacteria-immobilized cellulose acetate/poly (ethylene oxide) nanofibrous membrane for wastewater treatment. Scientific reports, **9(1)**, 18994.
5. Etim, E. E. (2012). Phytoremediation and its mechanisms: a review. Int J Environ Bioenergy, **2(3)**, 120-136.
6. Jeevanantham, S., Saravanan, A., Hemavathy, R. V., Kumar, P. S., Yaashikaa, P. R., & Yuvaraj, D. (2019). Removal of toxic pollutants from water environment by phytoremediation: a survey on application and future prospects. Environmental technology & innovation, **13**, 264-276.
7. Zamel, D., & Khan, A. U. (2021). Bacterial immobilization on cellulose acetate based nanofibers for methylene blue removal from wastewater: Mini-review. Inorganic Chemistry Communications, **131**, 108766.
8. Abbas, A., Al-Amer, A. M., Laoui, T., Al-Marri, M. J., Nasser, M. S., Khraisheh, M., & Atieh, M. A. (2016). Heavy metal removal from aqueous solution by advanced carbon nanotubes: critical review of adsorption applications. Separation and Purification Technology, **157**, 141-161.
9. Malik, D. S., Jain, C. K., & Yadav, A. K. (2017). Removal of heavy metals from emerging cellulosic low-cost adsorbents: a review. Applied water science, **7**, 2113-2136.
10. Kurade, M. B., Ha, Y. H., Xiong, J. Q., Govindwar, S. P., Jang, M., & Jeon, B. H. (2021). Phytoremediation as a green biotechnology tool for emerging environmental pollution: A step forward towards sustainable rehabilitation of the environment. Chemical Engineering Journal, **415**, 129040.
11. Álvarez, J. A., Ávila, C., Otter, P., Kilian, R., Istenič, D., Rolletschek, M. & Arias, C. A. (2017). Constructed wetlands and solar-driven disinfection technologies for sustainable wastewater treatment and reclamation in rural India: SWINGS project. Water Science and Technology, **76(6)**, 1474-1489.
12. Deutsche gesellschaft für internationale zusammenarbeit gmbh (GIZ). (2011). Technology review of constructed wetlands: subsurface flow constructed wetlands for greywater and domestic wastewater treatment. Sustainable sanitation-ecosan program.
13. DeNooyer, T. A., Peschel, J. M., Zhang, Z., & Stillwell, A. S. (2016). Integrating water resources and power generation: The energy–water nexus in Illinois. Applied energy, **162**, 363-371.
14. Istenic, D., Bodík, I., & Bulc, T. (2015). Status of decentralised wastewater treatment systems and barriers for implementation of nature-based systems in central and eastern Europe. Environmental Science and Pollution Research, **22**, 12879-12884.
15. Imam, S. (2017). Phytoremediation: a green method to combat environmental pollution. IJESRT, **6**, 418-421.
16. Niharika, S., Anita, G., Rajesh, V., Shyam, P., Vinay, M., & Kavit, S. (2019). Heavy metals uptake by AlceaRosea (Holly hock) using phytoremediation technology. Res. J. Chem. Environ, **23(6)**, 134-37.
17. Khan, X. U., & Khalil, N. (2017). Constructed Wetlands for Domestic Wastewater Treatment–A Promising Technology for Rural Areas in India. International Journal of Engineering Technology Science and Research, **4(6)**.

18. Vymazal, J., & Kröpfelová, L. (2015). Multistage hybrid constructed wetland for enhanced removal of nitrogen. Ecological Engineering, **84**, 202-208.
19. Biswal, B., Singh, S. K., Patra, A., & Mohapatra, K. K. (2022). Evaluation of phytoremediation capability of French marigold (Tagetes patula) and African marigold (Tagetes erecta) under heavy metals contaminated soils. International Journal of Phytoremediation, **24(9)**, 945-954.
20. Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. Ecological engineering, **35(1)**, 1-17.
21. Tilak, A. S., Wani, S. P., Patil, M. D., & Datta, A. (2016). Evaluating wastewater treatment efficiency of two field scale subsurface flow constructed wetlands. Current Science, 1764-1772.
22. Sudarsan, J. S., Roy, R. L., Baskar, G., Deeptha, V. T., & Nithiyanantham, S. (2015). Domestic wastewater treatment performance using constructed wetland. Sustainable Water Resources Management, **1**, 89-96.
23. El-Khateeb, M. A., Kamel, M., Megahed, R., & Abdel-Shafy, E. (2016). Sewage water treatment using constructed wetland with different designs. Pollut Res, **35(1)**, 197-201.
24. Machado, A. I., Beretta, M., Fragoso, R., & Duarte, E. D. C. N. F. D. A. (2017). Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil. Journal of environmental management, **187**, 560-570.
25. Selvamurugan, M., Doraisamy, P., Maheswari, M., & Akumar, N. B. (2011). Constructed wetlands for wastewater treatment: a review. Research & Reviews in BioSciences, **5(2)**, 100-105.
26. Shivhare, Niharika, & Roy, Momita, (2013). Gravel bed constructed wetland for treatment of sewage water. Pollution Research, **32(2)**, 415-419.
27. Kallimani, K. S., Virupakshi, A. S., Tech, M., & Sheshgiri, K. L. E. M. S. (2015). Comparison study on treatment of campus wastewater by constructed wetlands using Canna indica & Phragmites austrails plants. Research Journal of Engineering and Technology, **2(9)**, 44-50.
28. Jethwa, K., & Bajpai, S. (2016). Role of plants in constructed wetlands (CWS): a review. J. Chem. Pharm. Sci, **2**, 4-10.
29. Kouki, S., Saidi, N., Rajeb, A. B., & M'hiri, F. (2012). Potential of a polyculture of Arundo donax and Typha latifolia for growth and phytotreatment of wastewater pollution. African Journal of Biotechnology, **11(87)**, 15341-15352.
30. Liu, H., Hu, Z., Zhang, J., Ngo, H. H., Guo, W., Liang, S. & Wu, H. (2016). Optimizations on supply and distribution of dissolved oxygen in constructed wetlands: a review. Bioresource Technology, **214**, 797-805.
31. Pelissari, C., Guivernau, M., Viñas, M., de Souza, S. S., García, J., Sezerino, P. H., & Ávila, C. (2017). Unraveling the active microbial populations involved in nitrogen utilization in a vertical subsurface flow constructed wetland treating urban wastewater. Science of the total environment, **584**, 642-650.
32. Rai, U. N., Upadhyay, A. K., Singh, N. K., Dwivedi, S., & Tripathi, R. D. (2015). Seasonal applicability of horizontal sub-surface flow constructed wetland for trace elements and nutrient removal from urban wastes to conserve Ganga River water quality at Haridwar, India. Ecological engineering, **81**, 115-122.
33. Torrijos, V., Gonzalo, O. G., Trueba-Santiso, A., Ruiz, I., & Soto, M. (2016). Effect of by-pass and effluent recirculation on nitrogen removal in hybrid constructed wetlands for domestic and industrial wastewater treatment. Water research, **103**, 92-100.

34. Dhoble, Y. N., & Ahmed, S. (2018). Sustainability of wastewater treatment in subtropical region: aerobic vs anaerobic process. Int J Eng Res Dev, **14(1)**, 51-66.
35. Vijay, M. V., Sudarsan, J. S., & Nithiyanantham, S. (2017). Sustainability of constructed wetlands in using biochar for treating wastewater. Rasayan Journal of Chemistry, **10(3)**, 1056-1061.
36. Haberl, R. (1999). Constructed wetlands: a chance to solve wastewater problems in developing countries. Water Science and Technology, **40(3)**, 11-17.
37. Cooper, P. (1999). A review of the design and performance of vertical-flow and hybrid reed bed treatment systems. Water Science and Technology, **40(3)**, 1-9.
38. Brix, H. (1997). Do macrophytes play a role in constructed treatment wetlands? Water science and technology, **35(5)**, 11-17.