



Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.029>

CONSTRUCTED WETLANDS: STATE-OF-THE-ART WASTEWATER TREATMENT

Sanju Prajapat* and Bhagawatilal Jagetiya

Phytotechnology Research Lab, Department of Botany, M. L. V. Government College, Bhilwara - 311 001 (Rajasthan), India.

*Corresponding author E-mail : sanjuprajapat86@gmail.com

(Date of Receiving-28-05-2025; Date of Acceptance-06-08-2025)

ABSTRACT

Constructed wetlands (CWs) are among the recently established well-organized technologies have been used for various types of wastewater treatment for only last few decades. Compared to conventional treatment systems, constructed wetlands are low cost, simply operated, and easily maintained. As part of decentralized water treatment system CWs can be used which is a powerful technology with little operational prerequisites. Various types of wastewaters (municipal wastewater, industrial wastewater, agricultural wastewater, or/and landfill leachate) may be treated through the constructed wetlands. However, these systems have not found pervasive use, due to lack of awareness, and local skill in developing the technology on a local basis. This review summarizes the current methods used for wastewater treatment through constructed wetlands. Future, attention in choosing constructed wetlands as wastewater treating systems in developing countries are highlighted. Advantages and limitation of CWs have also been discussed in this article.

Key words : Constructed wetlands, Wastewater treatment, Municipal wastewater.

Introduction

“Constructed wetlands (CW) are engineered systems constructed and designed to operate the normal functions of wetlands vegetation, soil and their microbial populations to treat contaminants in surface water, ground water, or waste streams” (ITRC, 2003). CWs can be used as part of decentralized water treatment system and are a powerful technology with low operational requirements. These wetlands are being used for the treatment of various types of wastewaters e.g., municipal wastewater, industrial wastewater, agricultural wastewater, landfill leachate etc. The concept of constructed wetlands for wastewater treatment is not old. It started in 1960s in northern Germany by Kaithy Seidel (Vymazal, 2005). Kathe Seidel discoveries led to the first subsurface CW for municipal wastewater treatment in 1974 in the community of Liebenburg- Othfresen, Germany. She conducted many experiments using macrophyte on phenol, dairy and livestock wastewater (Seidel, 1976). Natural wetlands were in use before constructed wetlands.

Cooper and Boon (1995) reported the use of natural wetland for treatment of wastewater which was in practice in the United Kingdom for more than a century. The first free water surface CW (FWSCW) was set up in the Netherlands in 1967. Kickuth (1965) implemented this work in Europe in the late 1970s. Interest in the subject started in the United States started in early 1980 with the study of Wolverton *et al.* (1983) and Gersberg *et al.* (1985). Wetlands have been constructed with a number of cells, arranged in series and equivalent performance may be apply to individual cells or to combinations of cells. Parallel flow paths that are structurally autonomous are considered to be separate wetlands even though they may be adjoining to one another, and receive the same input water.

CWs treatment treats wastewater by utilizing normal processes provided by wetlands plants, soils, and microbial community (USEPA, 2004). CWs are designed to mimic natural systems and take advantage of many natural processes in a more controlled environment (Vymazal,

2005). CW treatment is engineered wastewater distillation system that contains chemical, biological, and physical processes, which are all similar to processes taking place in natural treatment wetlands (Scholz, 2006; Kayranli *et al.*, 2010; Abou-Elela *et al.*, 2013; Vymazal, 2014; Wu *et al.*, 2015; Pathak and Jagetiya, 2022). For ages, natural wetlands served as a convenient means of wastewater and sewage management which subsequently resulted in many forms of wetlands. It has been observed that natural wetlands were probably used for disposal of collected wastewater as far back as 1912 (Kadlec and Knight, 1996).

The aquatic natural treatment systems involve impounding wastewater in ponds or lagoons for sufficient period so that pollutants and pathogens in wastewater are removed through natural biological degradation processes. Floating plant species such as algae and water hyacinth may also be present in these systems to support the biological processes. In early days, use of constructed wetlands was limited to domestic and municipal sewage treatment, however after late 1980s use of CWs have been widened and being used in treating agricultural wastewater, food processing wastewater, heavy industry wastewater, mine drainage, land fill leachate and runoff water (Vymazal, 2005). CWs are becoming popular as decentralized wastewater treatment for smaller communities, where land is easily available and frequent power tripping prohibits the advocacy of highly mechanized plants. These systems have been proved for their treatment performance for physicochemical and microbiological contaminants removal. The wetlands plants species play the most critical role in determine the performance of the wetlands systems (Pathak and Jagetiya, 2023). The wetland plants govern multiple roles in CW during biological treatment of wastewater. They act as biological pumps controlling the oxygen transfer provide shelter to micro-fauna (microbes) governing the pollutants bio-degradation, uptake of recalcitrant contaminates etc. CWs offer several benefits, including low construction and operation cost, easy maintenance, reliable and effective wastewater treatment, stability under fluctuating hydro-logic and pollutant loading rates and potential other benefits such as aesthetics, flora and fauna habitats and enjoyments and educational purposes (Hammer and Bastian, 1989). Currently, the application of CWs in various wastewater purification system is popular all over the globe (Hoffman *et al.*, 2011; Abou-Elela and Hellal, 2012; Abou-Elela *et al.*, 2013; Vymazal, 2014; Wu *et al.*, 2015; Pathak and Jagetiya, 2025). Wetlands have long been valued for their ability to naturally purify water, acting as biological filters that eliminate

contaminants like nitrogen, sediments and heavy metals through mechanisms such as sedimentation, adsorption, ion exchange, and biodegradation (Dorido *et al.*, 2008; Razzouki *et al.*, 2015; Errich *et al.*, 2021; Abouri *et al.*, 2024).

CWs are used for treating various types of wastewaters e.g.; domestic wastewater (Bays and Knight, 2000; Coleman *et al.*, 2001), acid mine drainage (Would and Ngwenya, 2004; Hallberg and Johnson, 2005), agricultural wastewater (Hunt *et al.*, 2000; Smith *et al.*, 2006), landfill leachate (Domdush, 1989; Trautmann *et al.*, 1989), urban storm water (EPA, 1993) and for polishing advanced treated wastewater effluents for return to fresh water resources (Gschobl *et al.*, 1997; Schwartz *et al.*, 1998). Most of the CWs are applied for domestic sewage and municipal wastewater treatment and only few are used for industrial purposes (Dies *et al.*, 2006). Good aesthetic properties and effective treatment capabilities make sub-surface flow wetlands an appropriate choice for small-scale, individual or small group residential situations (Steiner and Combs, 1993; Hiley, 1995). Small-scale constructed wetlands for rural domestic wastewater treatment are a relatively new technology. In the 1960s, Seidel and Kickuth invented new horizontal-flow wetlands known as the "Root Zone Method" (RZM). This new system differed from the earlier Seidel design by having sticky substrate predominantly of clay soil and is the early wetland system used at Othfresen, Germany for municipal sewage treatment in 1974 (Kickuth, 1977; 1978; 1981; Brix, 1987; Vymazal, 2005, 2009). Furthermore, Kickuth advanced with the experimental research and disseminated this concept with his colleagues in Europe and led to the establishment of nearly 200 municipal and industrial wastewater treatment systems (Bastian and Hammer, 1993). The knowledge of potential for the application of the technology with regard to water pollution control and ecology enhancement needs to be disseminated and fully understood (Heers, 2006; Kamau, 2009; Abou-Elela *et al.*, 2013; Al-Baldawi *et al.*, 2014, 2015). In contrast, wetlands technology and its application in wastewater treatment has been practiced since the 1990s and the exploration of its research keeps increasing in other developing countries such as China (Xinshan *et al.*, 2010; Zhang *et al.*, 2012; Meng *et al.*, 2014; Song *et al.*, 2015) and India (Sheoran and Sheoran, 2006; Choudhary *et al.*, 2011; Sharma *et al.*, 2013; Pathak and Jagetiya, 2024).

Over the past decade, there has been a growing approval of the multiple values and functions of constructed wetlands, which are increasingly used for treating a variety of wastewaters (Goulet *et al.*, 2001;

Kadlec and Reddy, 2001). There are currently thousands of constructed wetlands worldwide receiving and treating a variety of municipal, industrial, and urban runoff wastewaters (Cameron *et al.*, 2003; Solano *et al.*, 2004). Recently, there has been increasing interest in Taiwan in utilizing the constructed wetlands as an alternative method for wastewater treatment because of its operational simplicity and cost efficiency (Kao *et al.*, 2001; Jing *et al.*, 2002; Lin *et al.*, 2002; Lee *et al.*, 2004). Although, the constructed wetland technology is well established, its application for treating specific industrial effluents has not been well documented (Kao and Wu, 2001; Garcia *et al.*, 2004; Amasa *et al.*, 2025).

Heavy metal (HMs) contamination is one of the most serious environment problems of the world. The CW was very effective in the removal of heavy metals from industrial wastewater and its removal performance was in order of $Cd > Cr > Fe > Pb > Cu > Ni$ (Khan *et al.*, 2009). The industrial sector has focused a great deal of attention on CW for removing heavy metals from its wastewater (Hadad *et al.*, 2006; Maine *et al.*, 2006; Jayaweera *et al.*, 2008; Porwal and Jagetiya, 2019). The CW system contains natural processes of aquatic macrophytes that not only accumulate pollutants directly into their tissues but also act as catalysts for purification reactions usually occur in the rhizosphere of the plants (Jenssen *et al.*, 1993). In rhizosphere, physicochemical and biological processes are induced by the interaction of plants, microorganisms and soil/sediments, to remove HMs from wastewater (Stottmeister *et al.*, 2003; Pathak and Jagetiya, 2024). Industrialization has contaminated the environments with HMs, particularly, in developing countries of the world, where advance treatment technologies are neither available nor affordable. The CWs, therefore, presents a cost effective and promising alternative for the treatment of industrial effluents. Previously, numerous studies have demonstrated that CWs have effectively removed HMs from wastewater (Mays and Edwards, 2001; Chen *et al.*, 2006; Hadad *et al.*, 2006; Pathak and Jagetiya, 2025).

The choice of plants is an important issue in CW, as they must survive the potentially toxic effects of the effluent and its variability. Common reeds (*Phragmites australis*), cattails (*Typha spp.*), bulrushes (*Scirpus spp.*) and reed canary grass (*Phalaris arundinacea* L.) have used for both domestic and industrial wastewater treatment (Shepherd *et al.*, 2001; Mbuligwe, 2005; Vymazal, 2005; Vymazal and Kropfelova, 2005; Porwal and Jagetiya, 2019). Coleman *et al.* (2001) observed significant differences among plant species in the treatment of wastewater and suggested that poly-cultures

(species mixtures) may perform better than mono-cultures.

In Portugal, the main macrophyte species used in CWs are *Cyperus spp.*; *Iris pseudacorus* (yellow iris), and *P. Australis* (Korkusuz, 2005). *Typha latifolia* (cattails), and *Phragmites australis* (common reed) are emergent macrophytes (vascular plants living in water or wetlands, either free-floating or attached to a surface) that commonly occur in natural wetlands. Since growth and efficiency of these macrophytes is thought to be stimulated by the high nutrient content of polluted waters (Brix and Carter, 1986) they would appear to be potentially suitable for wastewater amelioration studies. *Typha latifolia* is known to be tolerant of heavy metals, and is able to colonize industrially degraded habitats (Ye *et al.*, 1997). *Phragmites australis* may also be metal tolerant, either through total exclusion of elements, or storage of these elements in nontoxic forms in the tissues (Massaci *et al.*, 2001).

The most commonly used plant for HF constructed wetlands is *P. australis* (Kadlec and Knight, 1996; Vymazal *et al.*, 1998). *P. australis* is used throughout Canada, Europe, Australia and Africa (with the exception of its central part) and most parts of Asia (with the exception of India and Nepal). *P. karka* is used in Horizontal Flow Constructed Wetlands (HFCWs) in India and Nepal (Billore *et al.*, 2001, 2008; Bista *et al.*, 2004; Bista and Khatiwada, 2008; Singh *et al.*, 2009) and *Phragmites mauritianus* is used in central Africa (Byekwaso *et al.*, 2002). In the United States, common reed is considered an invasive and exotic plant species by wildlife agencies and natural resource. As a result, the use of this species has been limited in the United States (Wallace and Knight, 2006). A similar situation applies to New Zealand. Common reed is used for the treatment of municipal and domestic wastewater but has also been successfully used for HFCW treating various types of wastewaters e.g. textile industry, chemical industry etc.

Typha is often found in areas near water bodies, such as lakes, lagoons, and riverside areas, in many regions (Esteves *et al.*, 2008). *Typha* is a greatly flood-tolerant species that can allow internal pressurized gas flow to rhizomes because this species is characterized by a well-developed parenchyma system; this system provides oxygen for root growth in anaerobic substrates (Li *et al.*, 2010). Southern cattail (*T. domingensis*) is extremely salt resistant and considered as a potential source of pulp and fibre (Khider *et al.*, 2012). For other hand, *T. domingensis* is the plant species which has been used in treating industrial and urban effluents. Moreover,

this plant has been reported recently as a plant species with a high efficiency to accumulate metals when is used in wetland constructed (Teles Gomes *et al.*, 2014). For other hand, *T.domingensis* has been suggested as to remove high phosphorous concentrations from water to a biological mechanism (Di Luca *et al.*, 2015). This plant species has been suggested as a bio-monitor in phytoextraction technology in areas affected by some metals. Mojiri (2012) and Mojiri *et al.* (2013) used *T. domingensis* to remove metals from wastewater and leachates from landfill; indeed, it can effectively remove pollutants.

The main mechanisms of nutrient removal from wastewater in CWs are microbial processes such as nitrification and denitrification as well as physicochemical processes such as the fixation of phosphate by iron and aluminium in the soil filter (Pathak and Jagetiya, 2024). Moreover, plants are able to tolerate high concentrations of nutrients and heavy metals, and in some cases even to accumulate them in their tissues. The uptake of nitrogen into the plant biomass is also of minor importance from a technical viewpoint since harvesting the above ground biomass would remove only 5-10% of the nitrogen (Thable, 1984). Tanner (1996) estimated the nitrogen concentrations in helophytes in the above ground biomass to be between 15 and 32 mg N⁻¹ dry mass.

While a variety of removal mechanisms including adsorption, precipitation sedimentation, volatilization, filtration, and plant uptake are well documented (Kadlec and Knight, 1996), recognition that removal of most pollutants in treatment wetlands is due primarily to microbial activity has been a cornerstone of the technology almost from the opening (Reddy and D'Angelo, 1994; Hatano *et al.*, 1994; Kadlec and Knight, 1996). This is certainly true for removal especially soluble labile forms and organic carbon (OC) that dominate primary treated domestic wastewater. While plant uptake is a minor nitrogen removal mechanism, microbial transformations provide the majority of total nitrogen (TN) removal (Kadlec and Knight, 1996). Sulphate reduction has been recognized as an important mechanism for metals removal, but it may also play an important part in organic carbon removal and sulphide oxidation may also be an important process in CWs. Thus, pollutant removal and microbial activity in CW are closely tied to the cycling of carbon, nitrogen and sulphur (Dvorak *et al.*, 1992; Machemer and Wildeman, 1992).

Sources of Wastewaters in the Environment

Domestic Sewage

This includes wastewater generated by home

dwellings, public restrooms, hotels, restaurants, motels, resorts, schools, places of worship, sports stadiums, hospitals and other health centres, apartments etc. They all produce high volumes of wastewater.

Non-sewage

These include water from floods (stormwater), runoff (rainwater running through cracks in the ground and into gutters), swimming pools, car garages and cleaning centres. They also include laundromats, beauty salons, commercial kitchens, energy generation plants and so on. Wastewater is also generated from agricultural facilities, animal farms, washing harvested produce and cleaning farm apparatus.

Types of Wastewaters

Types of wastewaters (Fig. 1) are given in detail in the following paragraphs-

Domestic/Municipal Wastewater

This includes all wastewater generated by home dwellings, schools, hotels, public restrooms, restaurants, motels, places of worship, sports stadium, hospitals, military camps, recreation areas, holiday resorts and small industries and other health canterers, apartments and the like. They all produce high volume of wastewater. CWs are capable of efficiently treating domestic wastewater across a range of scales, from small rural communities to urban centres. They eliminate contaminants such as organic compounds, nutrients and pathogens by harnessing natural mechanisms, including microbial action, filtration, and sedimentation (Hammer, 2020).

Agricultural wastewater

Agricultural wastewater generated from a variety of farm activities including animal feeding operations and the processing of agricultural products, can pollute surface and ground water if not properly managed. Examples of agricultural wastewater include but are not limited to milking centre wash water, manure, barnyard and feedlot runoff, horse washing waters, egg washing and processing, slaughterhouse wastewaters, and runoff associated with composting. Additionally, runoff from croplands can contribute fertilizers, sediment, and pesticides into surface waters. Constructed wetlands are also effective in treating wastewater from agricultural fields and livestock feedlots, helping to minimize environmental pollution caused by fertilizers, pesticides, and animal waste (Patil *et al.*, 2021).

Industrial wastewater

Industries produce huge amount of waste which contains pollutants and toxic chemicals and which can

cause water pollution and damage to us and our environment. They contain pollutants such as nitrates, lead, asbestos, mercury, sulphur and many other dangerous chemicals. Various industries do not have proper waste management system and drain the waste in the fresh water which goes into rivers, canal and later in to sea. The toxic chemicals have the potential to change the colour of water, increase the amount of minerals, also known as eutrophication, change the temperature of water and pose serious hazard to water organisms. Constructed wetlands can be tailored to manage different types of industrial wastewater, with their design and operation depending on the nature of the pollutants involved. In some cases, pre-treatment is required to ensure effective performance (Stefanakis, 2018).

Stormwater Runoff (Storm Sewage)

This is precipitation (rain or melted snow) that flows over surfaces like roads, rooftops, and agricultural fields. As it flows, it picks up various pollutants, including, oils and greases from vehicles, sediments, sand and litter, road de-icing chemicals, animal waste, pesticides and fertilizers from lawns or fields. Constructed wetlands are effective in capturing and filtering stormwater runoff, thereby reducing the transport of pollutants into nearby rivers and streams. Additionally, they play a role in mitigating flood risks and controlling soil erosion (Pier *et al.*, 2015).

Conventional method verses Constructed Wetlands

Conventional methods	Constructed wetlands
They generally require short land areas	They generally require larger land areas
Costlier and less efficient	Low cost with higher efficiency
Have aesthetic values	They have no aesthetic values
These are natural wastewater systems	CW _s are artificial wastewater systems
These systems are lower productive Water saving efficacy low	These systems are highly productive Water saving efficacy high

Types of Constructed wetlands

Constructed wetlands are mainly following three types (Fig.2) depending upon flow of water-

Free Water Surface CW (FWSCW)

Subsurface Flow CW (SSFCW)

Hybrid Types

Free Water Surface Constructed Wetlands (FWSCW)

FWS wetlands technology started in North America with the ecological engineering of natural wetlands for



Fig. 1 : Types of wastewaters.

wastewater treatment at the end 1960s and beginning of 1970s. The constructed wetland, known as FWS system, can mimic natural systems as the water flows over the bed surface and is filtered through a dense stand of aquatic plants (Cooper *et al.*, 1999 and Jing *et al.*, 2002). An alternative system, known as the subsurface flow wetland, is also a constructed system consisting of an excavated but usually lined shallow basin containing gravel media and emergent aquatic plants (Mashauri *et al.*, 2000; Kao *et al.*, 2001; Garcia *et al.*, 2003; Kaseva, 2004). In 1968, FWSCW was created in Hungary near Keszthely in order to preserve the water quality of Lake Balaton and to treat wastewater of the town (Lakatos, 1998). The constructed wetlands were established in place of existing natural wetlands in peat soil. The capacity for wastewater purification by both natural and artificial wetlands is well documented (Spanglar *et al.*, 1976; Tiltom *et al.*, 1976; Gersbeg *et al.*, 1984). Typical FWS constructed wetlands with emergent macrophytes is a shallow sealed basins or sequence of basins, containing 20-30cm of rooting soil, with a water depth of 20-40cm (Vymazal *et al.*, 2006).

The most commonly used plant species for FWS constructed wetlands in Europe are- *Phragmites australis* and *Scirpus lacustris* in North America- *Typha* spp. And in Australia and New Zealand- *Scirpus* spp., and *Sagittaria latifolia*. FWSCWs operate like a natural wetland (Vymazal, 2006; El-Sheikh *et al.*, 2010; Stefanakis *et al.*, 2014; Wu *et al.*, 2014). The wetlands pool is shallow and sealed so that there is no wastewater seepage to the below ground aquifer. In terms of wastewater treatment, FWSCWs are very good for removal of suspended solids (SS), organic contaminants, nitrogen, pathogens and other contaminants such as heavy

metals (Kadlec and Knight, 1996; Vymazal, 2007; Kadlec and Wallace, 2009; Kotti *et al.*, 2010; Stefanakis *et al.*, 2014).

Subsurface Constructed Wetlands (SSFCW)

A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rocks or gravel. The water level is designed to remain below the top of the substrate. In most of the system in the United States, the flow path is horizontal, although some European system uses vertical flow paths. SSFCW is of two types: -

Vertical Flow CW (VSFCW)

Horizontal Flow CW (HSFCW)

Vertical Flow CW (VSFCWs) are wetland systems composed of a substrate media planted with macrophytes, which wastewater passes through for quality enhancement (Knowles *et al.*, 2011). VSFCWs were originally used and developed by Seidel in Germany, when she inserted them in between a septic tank and HSFCWs (Vymazal *et al.*, 2006; Vymazal and Kropfelova, 2011). The systems became pertinent in application gradually when people realized the inability of HSFCWs system to oxidize ammonia-nitrogen efficiently from wastewater as a result of limited oxygen in their substrate bed (Cooper, 1999; Vymazal, 2005; Stefanakis *et al.*, 2014; Vymazal, 2014). VF systems are mainly explored in Europe, particularly in France, Denmark, Austria, Germany, UK and USA (USEPA, 1995; Kadlec and Wallace, 2009).

Horizontal Flow CW (HSFCWs) are purification system where the movement of the wastewater is in a horizontal direction and it passes gradually through the filter substrate, macrophyte root and rhizomes till it reaches the outflow control valve where it is collected for sampling and analysis (Vymazal, 2009; 2013; 2014). HF system is composed of gravel, sand or their combination as a bed substrate, usually planted with reed and the wastewater passes horizontally from the inlet to the outlet beneath the porous substrate and plant root. HF systems are usually used in Europe and USA (Vymazal *et al.*, 2006; Vymazal, 2011; 2014) and require a small area when compared with FWS systems, but have high investment costs (Tsihrintzis *et al.*, 2007; Kadlec and Wallace, 2009).

Hybrid CW- Hybrid constructed wetlands are purification systems established mainly to achieve larger nitrogen removal by exploring the operational processes of denitrification and nitrification in vertical and horizontal flow systems together, concomitantly the wastewater (Vymazal, 2005; Vymazal and Kropfelova, 2011; Ayaz *et al.*, 2012; Vymazal, 2013; 2014). Presently, hybrid CW

are used globally for their ability to remove ammonia, nitrate and total nitrogen from various types of wastewaters (Vymazal, 2005; 2007; Ye and Li, 2009; Xinshan *et al.*, 2010; Vymazal and Kropfelova, 2011; Ayaz *et al.*, 2012; Vymazal, 2013; 2014). According to Vymazal (2013), hybrid constructed wetlands are categorized into the following combination: VF-HF systems, multistage VF-HF systems, VF hybrid systems, and hybrid constructed wetlands with FWSCW systems. He however, noted that VF-HF hybrid systems are marginally more effective in ammonia treatment than the other types of the hybrid systems.

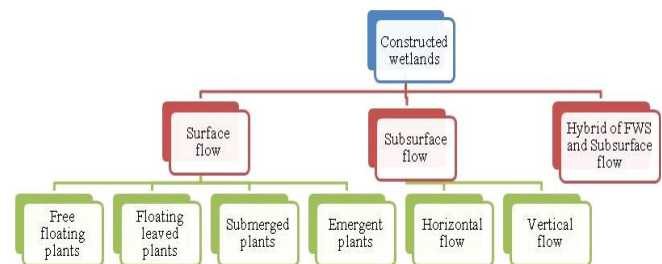


Fig. 2 : Types of constructed wetlands.

Soils previously used for agriculture are currently being converted to marshes with the hope that these constructed wetlands will function as nutrient sinks. Such systems are created in areas closest to sensitive aquatic systems. Flooding previously fertilized agricultural lands results in solubilisation of residual fertilizer nutrients such as inorganic phosphorus and their release into the overlying water column (D' Angelo and Reddy, 1994). To reduce P flux from soils it may be necessary to immobilize soluble P into non-available forms and reduce P flux into floodwater. This may be able by adding chemical amendments containing Ca, Fe, or Al that bind P into insoluble forms. The addition of chemicals to inactivate soluble phosphorus has long been used in advanced wastewater treatment (Ferguson and McCarty, 1971; Cooke and Kennedy, 1981) because of their efficiency in P removal and ease of application to wastewater (Balmer and Hultman, 1988). This technology was extended to immobilize contaminants in storm water retention ponds (Babin *et al.*, 1992) and restore extremely eutrophic lakes (Cooke *et al.*, 1986).

Vymazal (2016) studies the concentrations of heavy metals are usually much higher in the belowground than in aboveground biomass, especially in roots which are primary sites of uptake. This may be due to the conclusion that accumulation of heavy metals is higher in the belowground biomass. However, in cases, where the aboveground is much higher than belowground biomass the accumulation could be higher in the aboveground biomass. Concentration of phosphorus and nitrogen is

always higher in leaves than in stems. However, the stem biomass is mostly much higher in robust emergent species such as *Phragmites australis* and therefore, more nutrients can be stored in stems.

Lu *et al.* (2016), studies on medium filler play an important role in wetland sewage treatment processes. By carrying out a problem analysis of the treatment of traditional wetlands and useless operation, they design different constructed wetland fitters to treat rural household sewage. Using the same plants, they choose four different fitters, namely maifanite, steel slag, bamboo charcoal and limestone as substrates to build constructed wetland systems, and studies rural household sewage treatment in order to examine their effects on the degradation of pollutants. They observe the removal efficiencies obtain good effect. The theoretical maximum adsorption capacities of all these media are ordered as:

maifanite > steel slag > bamboo charcoal > limestone

Chandrakanth *et al.* (2016) studied on pilot scale constructed wetlands in treating a pretested domestic wastewater with selected plant species such as croton plants and *Typha latifolia*. Various kinds of constructed wetlands such as vertical flow type, horizontal flow type and hybrid type were tested. The characteristics such as BOD, COD, TSS, TS and TDS of effluents, treated with these pilot scale constructed wetlands were analyzed at different Hydraulic Retention Times (HRT). On observation, it was found that hybrid type constructed wetland exhibited the best removal efficiency in terms of all the characteristics of wastewater tested. Vingying *et al.* (2017), studied on aquatic macrophytes can indeed function as an efficient nutrient filter but only for low loading rates (polishing) and not for high rates (purification). The outcome of this controlled study not only contributes to our understanding of nutrient dynamics in constructed wetlands but also shows the differential effects of wetland types and plant species.

Fountoutakis *et al.* (2017) reported an improvement in the treatment of domestic wastewater via the use of halophyte planted CW. They showed that halophytes developed successfully in the constructed wetland and achieved pathogen removal efficiency and organic matter comparable to those reported for reeds in previous works (63% and 1.6 log units, respectively). Wang *et al.* (2017) studies on the applications of CWs for wastewater treatment in cold climate presents special challenges. Wetland treatment of wastewater relies largely on biological processes, and reliable treatment is often a function of climate conditions. To date, the rate of adoption

of wetland technology for wastewater treatment in cold regions has been slow and there are relatively few published reports on CW applications in cold climate. The efficiency of pollutant removal in constructed wetlands can decline at temperatures below 10°C, as low temperatures may slow down biological and microbial processes (Hu *et al.*, 2025).

Advantages and Limitation of Constructed Wetlands

Advantages

Long life and robustness : Renewable cycles of 15 years minimum renewable; if water nature changes, clean gravel and replace plants, but basic structure not in danger. Efficiency increases with time and ecosystem matures.

Low Cost : Compared to so-called conventional wastewater treatment plants.

Adaptability and Flexibility of treatment : Sizing depends of final use. All kinds of water, no limits of quantity, treatment units can be added as population grows, shape adjustable to site.

Simplicity and auto-organization : CW relies on biological complexity instead of forced mechanical or synthetic processes highly dependent on external energy sources.

Aesthetics : Great public spaces without additional cost.

Highly productive system and Water saving : Important added ecological value (ecosystem creation with CO₂ absorption, O₂ production, and wildlife habitat) as a new green zone is created at no extra water utilization

No additional pollution : No harmful products are used in the disinfection process nor contributing pollution. Protection of vital ecosystems such as rivers, lakes, oceans, groundwater sources and soils, as sizing is done according to required levels of water purification before release into the environment.

Limitations

They generally require larger land areas than do conventional wastewater treatment systems. Wetland treatment may be economical relative to other options only where land is available and affordable. The biological components are sensitive to toxic chemicals, such as ammonia and pesticides. Flushes of pollutants or surges in water flow may temporarily reduce treatment effectiveness. They require a minimum amount of water if they are to survive. While wetlands can tolerant temporally drawdown, they cannot withstand complete drying.

Author contribution

Sanju Prajapat was instrumental in the present research review, contributing to its design by establishing objectives and reporting. Dr. B.L. Jagetiya's involvement extended to crafting the manuscript, making the research accessible and impactful as the Research Supervisor.

Acknowledgement

Authors extend heartfelt thanks to the M.L.V. Government College, Bhilwara for extending amenities and support.

Competing interests

The authors declare no competing interests.

References

- Abou-Elala, S.I. and Hellal M.S. (2012). Municipal wastewater treatment using vertical flow constructed wetlands planted with *Canna*, *Phragmites* and *Cyperus*. *Ecol. Eng.*, **47**, 209-213.
- Abou-Elala, S.I., Golinielli G., Abou-Taleb E.M. and Hellal M.S. (2013). Municipal wastewater treatment in horizontal and vertical flows constructed wetlands. *Ecol. Eng.*, **61**, 460-468.
- Abouri, Y., Touzani A. and Khattabi A. (2024). Natural pollutant removal functions of Mediterranean wetlands: A review of recent findings. *Wetlands Ecol. Manage.*, **32**(1), 1–15.
- Akratos, C.S. and Tsihrantzis V.A. (2007). Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. *Ecol. Eng.*, **29**(2), 173-191.
- Al-Baldawi, I.A., Abdullah S.R.S., Anuar N., Hasan H.A. and Suja F. (2014). Phytoremediation of benzene and toluene in contaminated water using *Phragmites australis* in a constructed wetland system: Influence of plant roots and microbial activity. *International Biodeterioration & Biodegradation*, **90**, 64–70.
- Al-Baldawi, I.A., Abdullah S.R.S., Anuar N., Suja F. and Hasan H.A. (2015). Phytodegradation of total petroleum hydrocarbon (TPH) in diesel-contaminated water using *Scirpus grossus* in a floating treatment wetland system. *Environ. Sci. Poll. Res.*, **22**(5), 3880–3887.
- Amasa, W., Leta S. and Gnaro M.A. (2025). The application of Scoria-based horizontal subsurface flow constructed wetland for efficient textile wastewater treatment. *Results in Engineering*, 105495.
- AWWA, WEF. "APHA" (2005). *Standard Methods for the Examination of Water and Wastewater*, **21**, 4-15.
- Ayaz, S.C. et al. (2012). Effect of re circulation on nitrogen removal in a hybrid constructed wetland system. *Ecol. Eng.*, **40**, 1-5.
- Babin, B.J., Carter D.R. and Smith R.A. (1992). Use of chemical amendments to control phosphorus in stormwater ponds. *Water Environ. Res.*, **64**(5), 662–670.
- Bachand, P.A. and Horne J.A. (2000). Denitrification in constructed freewater surface wetland. II. Effects of vegetation and temperature. *Ecol. Eng.*, **14**, 17–32.
- Balmer, P. and Hultman B. (1988). Control of phosphorus discharges: present situation and trends. *Hydrobiologia*, **170**(1), 305-319.
- Bastian, R.K. and Hammer D.A. (1993). The use of constructed wetlands for wastewater treatment and recycling. In: Moshiri, G.A. (ed.). *Constructed wetlands for water quality improvement* (pp. 59–68). CRC Press.
- Bays, J.S. and Knight R.L. (2000). Removal of fecal coliform bacteria from domestic wastewater in a constructed wetland. *Water Environ. Res.*, **72**(2), 240–247.
- Bays, J.S., Knight R.L., Wenkert L., Clarke R. and Gong S. (2001). Progress in the research and demonstration of Everglades periphyton-based stormwater treatment areas. *Water Sci. Technol.*
- Billore, S.K., Singh N., Ram H.K., Sharma J.K., Singh V.P., Nelson R.M. and Das P. (2001). Treatment of a molasses based distillery effluent in a constructed wetland in central India. *Water Sci. Technol.*, **44**(11/12), 441–448.
- Billore, S., Prashant K., Sharma J.K., Singh N., Ram H., Dass P. and Jain R. (2008). Restoration and conservation of stagnant water bodies by gravel-bed treatment wetlands and artificial floating reed beds in tropical India. In : Billore, S., Dass P. and Vymazal J. (eds). *Proceedings of 11th International Conference on Wetland Systems for Water Pollution Control*, Vol. 1. Institute of Environment Management and Plant Sciences, Vikram University, Ujjain, 408–414.
- Bista, K.R. and Khatiwada N.R. (2008). Assessment of reed bed technology for wastewater treatment in Nepal. In Billore, S., Dass P. and Vymazal J. (eds). *Proceedings of 11th International Conference on Wetland Systems for Water Pollution Control*, Vol. 1. Institute of Environment Management and Plant Sciences, Vikram University, Ujjain, 1124–1129.
- Bista, K.R., Sharma P., Khatiwada N.R. and Bhattarani K.K. (2004). Cost effective design of horizontal reed beds treating wastewater in Nepal. In : *Proceedings of 9th International Conference on Wetland Systems for Water Pollution Control*. ASTEE and Cemagref, Lyon, 299–305.
- Bøezinovi, T. and Vymazal J. (2014). Competition of *Phragmites australis* and *Phalaris arundinacea* in constructed wetlands with horizontal subsurface flow—does it affect BOD 5, COD and TSS removal? *Ecol. Eng.*, **73**, 53-57.
- Brix, H. and Carter V. (1986). An overview of the hydrologic concerns related to wetlands in the United States. *Can. J. Bot.*, **64**, 364-374.
- Brix, H. (1987). Treatment of wastewater in the rhizosphere of wetland plants—the root-zone method. *Water Sci. Technol.*, **19**(1-2), 107-118.
- Brix, H. (1993). Wastewater treatment in constructed wetlands: system design, removal processes, and treatment performance. *Constructed wetlands for water quality improvement*. 9-22.

- Byekwaso, E., Kansiime F., Logstrum J. and Andersen S. (2002). The optimization of a reed bed filter for effluent treatment at Kasese Cobalt Company Limited, Uganda. In: *Proceedings of 8th International Conference on Wetland Systems for Water Pollution Control*. University of Dar es Salaam, Tanzania, 660–668.
- Cameron, K., Madramootoo C., Crolla A. and Kinsley C. (2003). Pollutant removal for municipal sewage lagoon effluents with a free-surface wetland. *Water Res.*, **37**, 2803–2812.
- Chandhran, G., Srimurali M. and Vivek Vardhan C.M. (2016). A Study on Domestic Wastewater Treatment by Pilot-Scale Constructed Wetlands. *Int. J. Chem. Tech Res.*, **9(6)**, 376–383.
- Chen, T.Y., Kao C.M., Yeh T.Y., Chien H.Y. and Chao A.C. (2006). Application of a constructed wetland for industrial wastewater treatment: A pilot-scale study. *Chemosphere*, **64**, 497–502.
- Choudhary, A.K., Kumar S. and Sharma C. (2011). Constructed wetlands: an option for pulp and paper mill wastewater treatment. *Elect. J. Environ., Agricult. Food Chem. (EJEAFCh)*, **10(10)**, 3023–3037.
- Coleman, J., Hench K., Garbutt K., Sexstone A., Bissonnette G. and Skousen J. (2001). Treatment of domestic wastewater by three plant species in constructed wetlands. *Water, Air and Soil Poll.*, **128(3)**, 283–295.
- Cooke, G.D. and Kennedy R.H. (1981). Phosphorus removal in wastewater treatment: Chemical methods. *Water Res.*, **15(6)**, 613–624.
- Cooke, G.D., Welch E.B., Peterson S.A. and Nichols S.A. (1986). Restoration and management of lakes and reservoirs. *Lewis Publishers*.
- Cooper, P. and Green B. (1995). Reed bed treatment systems for sewage treatment in the United Kingdom—the first 10 experience. *Water Sci. Technol.*, **32.3**, 317–327.
- Cooper, Paul (1999). A review of the design and performance of vertical-flow and hybrid reed bed treatment systems. *Water Sci. Technol.*, **40.3**, 1–9.
- Copper, P.F., Job G.D., Green M.B. and Shutes R.B.E. (1996). Reed beds and constructed wetlands for wastewater treatment. WRC publication, Medmenham, Marlow.
- D'Angelo, E.M. and Reddy K.R. (1994). Diagenesis of organic matter in a wetland receiving hypereutrophic lake water: II. Role of inorganic electron acceptors in nutrient release. *J. Environ. Qual.*, **23(5)**, 937–943.
- Di Luca, G.A., Mufarrije M.M. and Hadad H.R. (2015). Phosphorus removal from eutrophic water using *Typhadomingensis* in a constructed wetland system. *Ecolog. Engg.*, **83**, 307–313.
- Dias, V.N., Canseiro C., Gomes A.R., Correia B. and Bicho C. (2006). Constructed wetlands for wastewater treatment in Portugal: a global overview. In: *Proceedings of 10th International Conference on Wetland Systems for Water Pollution Control*. MAOTDR.91–101.
- Dies, J., Siciliano A., Puigagut J. and Salvado H. (2006). Domestic wastewater treatment in vertical flow constructed wetlands with granular media and *Phragmites australis*. *Water Sci. Technol.*, **54(11–12)**, 191–197.
- Domdus, E. (1989). Constructed wetlands for landfill leachate treatment: A field study. *J. Environ. Quality*, **18(2)**, 181–186.
- Dorado, A., Lloveras M., Puigdomènech C. and Girbal J. (2008). Wetlands and water quality: Natural processes and human impacts. *Environ. Res. J.*, **12(3)**, 145–157.
- Dvorak, B.I., Zehnder A.J.B. and Goerlitz D.F. (1992). Microbial sulfur cycling in constructed wetlands. *Water Sci. Technol.*, **26(7–8)**, 1573–1580.
- El-Sheikh, A.H., Shalaby N.A., El-Zehery O.E. and Al-Asheh S. (2010). Performance of free water surface constructed wetlands for domestic wastewater treatment. *Desalination*, **262(1–3)**, 189–195.
- EPA, U. (1993). Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. *Development*.
- Erich, A., Bouguerra M. and Nouira S. (2021). The contribution of wetlands to water purification in semi-arid environments. *J. Environ. Manage.*, **292**, 112735.
- Esteves, B.S., Enrich-Prast A. and Suzuki M.S. (2008) Allometric relations for *Typhadomin gensis* natural populations. *Acta Limnol. Bras.*, **20 (4)**, 305–311.
- Ferguson, J.F. and McCarty P.L. (1971). Chemical precipitation of phosphorus. *J. (Water Pollution Control Federation)*, **43(8)**, 1751–1770.
- Fountoulakis, M.S., Daskalakis G., Papadaki A., Kalogerakis N. and Manios T. (2017). Use of halophytes in pilot-scale horizontal flow constructed wetland treating domestic wastewater. *Environ. Sci. Pollut. Res.* 1–8.
- Fountoutakis, S., Tsihrintzis V.A. and Kotsou M.D. (2017). Treatment of domestic wastewater using halophyte-planted constructed wetlands. *Ecolog. Engg.*, **105**, 192–201.
- Garcia, J., Aguirre P., Mujeriego R., Huang Y., Ortiz L. and Bayona J. (2004). Initial contaminant removal performance factors in horizontal flow reed beds used for treating urban wastewater. *Water Res.*, **38**, 1669–1678.
- Garcia, J., Ojeda E., Sales E., Chico F., Piriz T., Aguirre P. and Mujeriego R. (2003). Spatial variations of temperature, redox potential and contaminants in horizontal flow reed beds. *Ecol. Eng.*, **21**, 129–142.
- Gersberg, R.M., Elkins B.V., Goldman C.R. and Sayler G.S. (1984). Role of aquatic plants in wastewater treatment by artificial wetlands. *Water Res.*, **18(2)**, 177–183.
- Gersberg, R.M., Elkins B.V. and Goldman C.R. (1985). Wastewater treatment by artificial wetlands. *Water Sci. Technol.*, **17(4–5)**, 443–450.
- Gopal, B. (1999). Natural and constructed wetland for wastewater treatment—potentials and problems. *Water Sci. Technol.*, **40**, 27–35.
- Goulet, R.R., Pick F.R. and Droste R.L. (2001). Test of the first-order removal model for metal retention in a young

- constructed wetland. *Ecol. Eng.*, **17**, 357–371.
- Green, M., Friedler E., Ruskol Y. and Safrai I. (1997). Investigation of alternative method for nitrification in constructed wetlands. *Water Sci. Technol.*, **35**(5), 63–70.
- Green, M.B., Griffin P., Seabridge J.K. and Dhoibie D. (1997). Removal of bacteria in subsurface flow wetland. *Water Sci. Technol.*, **35**, 109–116.
- Gschlobl, T., Michel I., Heiter M., Nerger C. and Rehbein V. (1997). Microscopic and enzymatic investigations on biofilms of wastewater treatment systems. *Water Sci. Technol.*, **36**(1), 21–30.
- Hadad, H.R., Maine M.A. and Bonetto C.A. (2006). Macrophyte growth in a pilot-scale constructed wetland for industrial wastewater treatment. *Chemosphere*, **63**, 1744–1753.
- Hammer, D.A. (2020). *Constructed wetlands for wastewater treatment: Municipal, industrial and agricultural*. CRC Press.
- Hammer, Donald A. and Bastian R.K. (1989). Wetland ecosystems: Natural water purifiers? *Constructed wetlands for wastewater treatment: municipal, industrial and agricultural* 519.
- Hatano, K., Gross M.A. and Ogata Y. (1994). Role of microorganisms in wastewater treatment using constructed wetlands. *Water Sci. Technol.*, **29**(4), 17–26.
- Heers, M. (2006). Constructed wetlands under different geographic conditions: Evaluation of the suitability and criteria for the choice of plants including productive species. *Hamburg Univ. Appl. Sci., Germany Faculty of Life Sciences*.
- Hiley, P.D. (1995). The reality of sewage treatment using wetlands. *Water Sci. Technol.*, **32**(3), 329–338.
- Hu, Z., Wang S., Ji M., Xu X. and Tanveer M. (2025). New experiences to enhance the treatment efficiency of constructed wetlands in cold climates. In: *Emerging Developments in Constructed Wetlands* (pp. 579–594). Elsevier.
- Hunt, P.G., Poach M.E., Szogi A.A. and Reddy G.B. (2000). Treatment of swine wastewater in constructed wetlands. *Water Sci. Technol.*, **44**(11–12), 545–550.
- ITRC (2003). Interstate Technology Regulatory Council Wetlands Team, USA (www.itrcweb.org/guidancedocument.asp?TID=24)
- Jagetiya, B. and Porwal S.R. (2019). Exploration of floral diversity of polluted habitats around Bhilwara city for phytoremediation.
- Jayaweera, M.W., Kasturiarachchi J.C., Kularatne R.K.A. and Wijeyekoon S.L.J. (2008). Contribution of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) grown under different nutrient conditions to Fe-removal mechanisms in constructed wetlands. *J. Environ. Manage.*, **87**, 450–460.
- Jenssen, P.D., Krogstad T. and Mahlum T. (1993). *Potential Use of Constructed Wetland for Wastewater Treatment in Northern Environment*. Department of Soil Science, Agricultural University of Norway, Norway. N-1432 As.
- Jing, S.R., Lin Y.F., Lee D.Y. and Wang T.W. (2001). Nutrient removal from polluted river water by using constructed wetlands. *Bioresour. Technol.*, **76**, 131–135
- Jing, S.R., Lin Y.F., Lee D.Y. and Wang T.W. (2002). Microcosm wetland for wastewater treatment with different hydraulic loading rates and macrophytes. *J. Environ. Qual.*, **31**, 690–696.
- Johnson, D.B. and Hallberg K.B. (2005). Acid mine drainage remediation options: a review. *Sci. Total Environ.*, **338**(1), 3–14.
- Kadlec, R.H. and Wallace S.D. (2009). *Treatment wetlands*. 2nd edition. CRC Press, Boca Raton, FL, USA. 1016.
- Kadlec, R.H. and Knight R.L. (1996). *Treatment wetlands*. CRC. Boca Raton, FL.
- Kadlec, R.H. (2009). Comparison of free water and horizontal subsurface treatment wetlands. *Ecol. Eng.*, **35**(2), 159–174.
- Kadlec, R.H. and Reddy K.R. (2001). Temperature effects in treatment wetlands. *Water Environ. Res.*, **73**, 543–557.
- Kamau, C. (2009). Constructed wetlands: potential for their use in treatment of grey water in Kenya. *Unpublished MSc thesis*, Christian-Albrechts University, Kiel, Germany.
- Kao, C.M., Wang J.Y., Lee H.Y. and Wen C.K. (2001). Application of a constructed wetland for non-point source pollution control. *Water Sci. Technol.*, **44**, 585–590.
- Kaseva, M. (2004). Performance of a sub-surface flow constructed wetland in polishing pre-treated wastewater—a tropical case study. *Water Res.*, **38**, 681–687.
- Kayranli, B., Scholz M., Mustafa A., Hofmann O. and Harrington R. (2010). Performance evaluation of integrated constructed wetlands treating domestic wastewater. *Water, Air and Soil Pollution*, **210**(1–4), 435–451.
- Khalil, N., Mittal A.K., Raghav A.K. and Rajeev S. (2006). UASB Technology for Sewage treatment in India: 20 years experience. *Environ. Engg. Manage. J. (EEMJ)*, **5**(5).
- Khan, S., Ahmad I., Shah M.T., Rehman S. and Khaliq A. (2009). Use of constructed wetland for the removal of heavy metals from industrial wastewater. *J. Environ. Manage.*, **90**(11), 3451–3457.
- Khider, T.O., Yusof A.M., Hassan M.A. and Yahya R. (2012). Evaluation of *Typhadomin gensis* as a renewable source for pulp and paper production. *BioResources*, **7**(3), 3847–3861.
- Khider, T.O., Omer S. and Taha O. (2012). Alkaline pulping of *Typhadomingensis* stems from Sudan. *World Appl. Sci. J.*, **16** (3), 331–336.
- Kickuth, R. (1977). Degradation and incorporation of nutrients from rural wastewaters by plant rhizosphere under limnic conditions. Utilization of manure by land spreading, London, United Kingdom, 335–343.

- Kickuth, R. (1965). Bhosphorus mobilization in the rhizosphere. *Sonderh. Landw. Forseh*, **12**, 103-109.
- Kickuth, R. (1982). A low-cost process for purification of municipal and industrial wastewater. *Der Tropenlandwirt-J. Agriculture in the Tropics and Subtropics*, **83(2)**, 141-154.
- Kivaisi, A.K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecol. Eng.*, **16(4)**, 545-560.
- Kleinmann, R.L.P. and Girts M.A. (1987). Acid mine water treatment in wetlands: an overview of an emergent technology.
- Knight, R.L., Ruble R.W., Kadlec R.H. and Reed S. (1993). Wetlands for wastewater treatment: performance database. *Constructed wetlands for water quality improvement*, 35-35.
- Knowles, P., Dotro G., Nivala J. and García J. (2011). Clogging in subsurface -flow treatment wetlands: occurrence and contributing factors. *Ecol. Eng.*, **37(2)**, 99-112.
- Korkusuz, E.A. (2005). Manual of practice on constructed wetlands for wastewater treatment and reuse in Mediterranean countries. Report AVKR, 5.
- Kotti, I.P., Gikas G.D. and Tsihrantzis V.A. (2010). Effect of operational and design parameters on removal efficiency of pilot-scale FWS constructed wetlands and comparison with HSF systems. *Ecol. Eng.*, **36(7)**, 862-875.
- Lakatos, G. (1998). The history and development of constructed wetlands in Hungary. *Water Sci. Technol.*, **37(3)**, 99-106.
- Lee, C.Y., Lee C.C., Lee F.Y., Tseng S.K. and Liao C.J. (2004). Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads. *Bioresour. Technol.*, **92**, 173-179.
- Li, S., Lissner J., Mendelssohn L.A., Brix H., Lorenzen B., McKee K.L. and Miao S. (2010). Nutrient and growth responses of cattail (*Typhadomin gensis*) to redox intensity and phosphate availability. *Ann. Bot.*, **105**, 175-184.
- Li, X. and Jiang D. (1995). Constructed wetland systems for water pollution control in North China. *Water Sci. Technol.*, **32**, 349-356.
- Li, Y., Guan B., Zhou D., Peng Y., Wang P. and Gao Y. (2010). Growth and physiological responses of *Typha latifolia* L. to salinity. *Environ. Exp. Bot.*, **68(2)**, 139-146.
- Lin, Y.F., Jing S.R., Lee D.Y. and Wang T.W. (2002). Nutrient removal from aquaculture wastewater using a constructed wetlands system. *Aquaculture*, **209**, 169-184.
- Lu, S., Zhang X., Wang J. and Pei L. (2016). Impacts of different media on constructed wetlands for rural household sewage treatment. *J. Cleaner Prod.*, **127**, 325-330.
- Lu, S., Zhang Z., Wang Z. and Chen Y. (2016). Effects of different substrates on pollutant removal in constructed wetlands treating rural household sewage. *Ecolog. Engg.*, **95**, 49-56.
- Machemer, S.D. and Wildeman T.R. (1992). Adsorption compared with sulfide precipitation as metal removal processes from acid mine drainage in a constructed wetland. *J. Contam. Hydrol.*, **9(1-2)**, 115-131.
- Maine, M.A., Sun'e N., Hadad H., Sa'nchez G. and Bonetto C. (2006). Nutrient and metal removal in a constructed wetland for wastewater treatment from a metallurgic industry. *Ecol. Eng.*, **26**, 341-347.
- Mashauri, D.A., Mulungu D.M. and Abdulhussein B.S. (2000). Constructed wetland at the University of Dar Es Salaam. *Water Res.*, **34**, 1135-1144.
- Massaci, A., Piertini F. and Iannelli M.A. (2001). Remediation of wetlands by *Phragmites australis*. *Minerva Biotechnol.*, **13**, 135-140.
- Mays, P.A. and Edwards G.S. (2001). Comparison of heavy metals accumulation in a natural wetland and constructed wetlands reserving acid mine drainage. *Ecolog. Engg.*, **16**, 487-500.
- Mbuligwe, S.E. (2005). Comparative treatment of dye-rich wastewater in engineered wetland systems (EWSs) vegetated with different plants. *Water Res.*, **39(2)**, 271-280.
- Meng, P., Pei H., Hu W., Shao Y. and Li Z. (2014). How to increase microbial degradation in constructed wetlands: influencing factors and improvement measures. *Biores. Technol.*, **157**, 316-326.
- Mojiri, A. (2012). Phytoremediation of heavy metals from municipal wastewater by *Typhadomingensis*. *Afr. J. Microbiol. Res.*, **6(3)**, 643-647.
- Mojiri, A., Aziz H.A., Zahed M.A., Aziz S.Q. and Selamat R.B.M. (2013). Phytoremediation of heavy metals from urban waste leachate by southern Cattail (*Typhadomin gensis*). *Int. J. Sci. Res. Environ. Sci.*, **1 (4)**, 63-70.
- NIC.National Informatics Centre (2006). Ministry of Communication and Information Technology Collectorate, Bhilwara - 311 001, Rajasthan 2006. Geographical position. e-mail:dm-bhi@raj.nic.in, dio-bhi@raj.nic.in.
- Pathak, S. and Jagetiya B.L. (2022). A review on constructed wetlands. *Mukt Shabd J.*, **11(7)**, 945-955.
- Pathak, S. and Jagetiya B.L. (2024). Isolation and characterization of indigenous bacterial strains from constructed wetland with biofertilizer potential. *J. Chem. Hlth Risks*, **14 (6)**, 26-37.
- Pathak, S. and Jagetiya B.L. (2024). Studies of wastewater management through microbiology of constructed wetland. *J. Adv. Sci. Technol.*, **21 (1)**, 79-91.
- Pathak, S. and Jagetiya B.L. (2025). Constructed Wetlands: An Effective Strategy for Treating Domestic and Agricultural Rural Sewages. In: *Rural Economy and Sustainable Development* (Eds. Jagetiya, B.L., Saurabh Singh and Chetna Kumawat). pp. 117-126 Scientific Publishers India, New Delhi, India.
- Pathak, S. and Jagetiya B.L. (2023). Wastewater Treatment Using Constructed Wetland. *J. Adv. Sci. Technol.*, **20(1)**, 5-9.

- Patil, S.S., Kulkarni V.G. and Deshmukh P.D. (2021). Role of constructed wetlands in managing agricultural runoff and livestock waste. *J. Environ. Manage.*, **285**, 112121.
- Pier, B., Harlan S.L. and Chang H. (2015). Stormwater management using constructed wetlands: Protecting urban waterways and reducing flood risk. *Environ. Sci. Policy*, **52**, 115–123.
- Razzouki, Z., El Fad'z M. and Ouhammou A. (2015). Wetlands as natural wastewater treatment systems: Case studies and future perspectives. *Ecolog. Engg.*, **82**, 50–59.
- Reddy, K.R. and D'angelo E.M. (1994). Soil processes regulating water quality in wetlands. *Global wetlands: Old world and new*, 309–324.
- Rivera, F., Warren A., Curds C.R., Robles E., Gutierrez A., Gallegos E. and Calderón A. (1997). The application of the root zone method for the treatment and reuse of high-strength abattoir waste in Mexico. *Water Sci. Technol.*, **35(5)**, 271–278.
- Scholz, M. (2006). *Wetland systems to control urban runoff*. Elsevier.
- Schreijer, M., Kampf R., Toet S. and Verhoeven J. (1997). The use of constructed wetlands to upgrade treated sewage effluents before discharge to natural surface water in texel island, The Netherlands—pilot study. *Water Sci. Technol.*, **35(5)**, 231–237.
- Schwartz, J.J., Waterman A.B., Lemley A.T., Wagenet L.P., Landre P. and Alee D.J. (1998). Homeowner perceptions and management of private water supplies and wastewater treatment systems. *J. Soil Water Conser.*, **53(4)**, 315–319.
- Seidel, K. (1976). Macrophytes and water purification. *Biological Control of Water Pollution* (Edited by Tourbier J. and Pierson R.W. Jr.), 109–112.
- Sharma, P.K., Takashi I., Kato K., Ietsugu H., Tomita K. and Nagasawa T. (2013). Effects of load fluctuations on treatment potential of a hybrid sub-surface flow constructed wetland treating milking parlor wastewater. *Ecol. Eng.*, **57**, 216–225.
- Sheoran, A.S. and Sheoran V. (2006). Heavy metal removal mechanism of acid mine drainage in wetlands: a critical review. *Minerals Engineering*, **19(2)**, 105–116.
- Shepherd, H.L., Tchobanoglous G. and Grismer M.E. (2001). Time dependent retardation model for chemical oxygen demand removal in a subsurface-flow constructed wetland for winery wastewater treatment. *Water Environ. Res.*, **73(5)**, 597–606.
- Singh, S., Haberl R., Moog O., Shrestha R.R., Shrestha P. and Shrestha R. (2009). Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high strength wastewater in Nepal – A model for DEWATS. *Ecol. Eng.*, **35**, 654–660.
- Smith, E., Gordon R., Madani A. and Stratton G. (2006). Year-round treatment of dairy wastewater by constructed wetlands in Atlantic Canada. *Wetlands*, **26(2)**, 349–357.
- Solano, M., Soriano P. and Ciria M. (2004). Constructed wetlands as a sustainable solution for wastewater treatment in small villages. *Biosyst. Eng.*, **87**, 109–118.
- Spangler, F., Sloey W. and Fetter C.W. (1976). Experimental use of emergent vegetation for the biological treatment of municipal wastewater in Wisconsin. *J. Biological Control of Water Pollution*. Tourbier and R.W. Pierson, Jr., eds.
- Spangler, M.G., Patrick R. and McComb A. (1976). Treatment of municipal wastewater using natural wetland systems. *Water Poll. Control Federation J.*, **48(3)**, 596–603.
- Staubitz, W.W., Surface J.M., Steenhuis T.S., Peverly J.H. and Lavine M.J. (1989). Potential use of constructed wetlands to treat landfill leachate. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural*. Lewis Publishers, Chelsea Michigan, 735–742.
- Stefanakis, A.I. (2018). *Constructed wetlands for industrial wastewater treatment*. Wiley.
- Stefanakis, A., Akratos C.S. and Tsihrintzis V.A. (2014). Vertical flow constructed wetlands: Eco-engineering systems for wastewater and sludge treatment. Newnes.
- Steiner, G.R. and Combs D.W. (1993). Small constructed wetlands system for domestic wastewater treatment and their performance. *Constructed wetlands for water quality improvement*, 491–498.
- Stottmeister, U., Wiebner A., Kusch P. and Kappelmeyer U. (2003). Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotechnol. Adv.*, **22**, 93–117.
- Tang, Y., Harpenslager S.F., van Kempen M.M., Verbaarschot E.J., Loeffen L.M., Roelofs J.G., Smolders A.J. and Lamers L.P. (2017). Aquatic macrophytes can be used for wastewater polishing but not for purification in constructed wetlands. *Biogeosciences*, **14(4)**, 755.
- Tanner, C.C. (1996). Plants for constructed wetland treatment systems—a comparison of the growth and nutrient uptake of eight emergent species. *Ecol. Eng.*, **7(1)**, 59–83.
- Teles Gomes, M.V., Rodriguez de Souza R., Silva Teles V. and Araujo Mendes E. (2014). Phytoremediation of water contaminated with mercury using *Typhadomingensis* in constructed wetland. *Chemosphere*, **103**, 228–233.
- Thable, L. (1984). Nutrient removal efficiency in wetland vegetation: A technical assessment. *J. Environ. Qual.*, **13(3)**, 289–294.
- Tilmon, R.L., Rehm G. and Smith R. (1976). Application of wetlands for wastewater treatment. *Environ. Sci. Technol.*, **10(4)**, 359–364.
- Tilton, D.L., Kadlec R.H. and Richardson C.J. (1976). Freshwater wetlands and sewage effluent disposal. In: *Proc. Symp.*, May.
- Trautmann, N.M., Krasny M.E. and Porter K.S. (1989). Constructed wetlands for treating landfill leachate. *Waste Manage. Res.*, **7(4)**, 299–306.
- U.S. Environmental Protection Agency (USEPA) (2004).

- Constructed treatment wetlands* (EPA/843-H-04-017). U.S. Environmental Protection Agency, Office of Water.
- U.S. Environmental Protection Agency (1995b). Report to Congress on Flow Control and Municipal Solid Waste, Report No. EPA 530-4-95-008 (Washington, DC: U.S. EPA/ Office of Solid Waste, Municipal and Industrial Solid Waste Division, March).
- US EPA (2004). *Guidelines for Water Reuse*. U.S. Environmental Protection Agency, Report No. EPA/625/R-04/108, Cincinnati, OH, USA, 445.
- Vingying, C., Smith J. and Lee H. (2017). Nutrient dynamics and the role of aquatic macrophytes in constructed wetlands: Implications for treatment efficiency. *Ecolog. Engg.*, **102**, 65–73.
- Vymazal, J. (2011). Long-term performance of constructed wetlands with horizontal sub-surface flow: Ten case studies from the Czech Republic. *Ecol. Eng.*, **37(1)**, 54–63.
- Vymazal, J. (ed.) (1998). *Constructed wetlands for wastewater treatment in Europe*. Backhuys Publ.
- Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. *Sci Total Environ.*, **380(1)**, 48–65.
- Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecol. Eng.*, **35(1)**, 1–17.
- Vymazal, J. (2013). Emergent plants used in free water surface constructed wetlands: a review. *Ecol. Eng.*, **61**, 582–592.
- Vymazal, J. (2014). Constructed wetlands for treatment of industrial wastewaters a review. *Ecol. Eng.*, **73**, 724–751.
- Vymazal, J. and Kröpfelová L. (2005). Growth of *Phragmites australis* and *Phalaris arundinacea* in constructed wetlands for wastewater treatment in the Czech Republic. *Ecol. Eng.*, **25(5)**, 606–621.
- Vymazal, J. and Kröpfelová L. (2011). A three-stage experimental constructed wetland for treatment of domestic sewage: first 2 years of operation. *Ecol. Eng.*, **37(1)**, 90–98.
- Vymazal, J. (2013). The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: a review of a recent development. *Water Res.*, **47(14)**, 4795–4811.
- Vymazal, J. (2014). Constructed wetlands for treatment of industrial wastewaters: a review. *Ecol. Eng.*, **73**, 724–751.
- Vymazal, J. (2016). Concentration is not enough to evaluate accumulation of heavy metals and nutrients in plants. *Sci. Total Environ.*, **544**, 495–498.
- Vymazal, J., Brix H., Cooper P.F., Haberl R., Perfler R. and Laber J. (1998). Removal mechanisms and types of constructed wetlands. Constructed wetlands for wastewater treatment in Europe, 17–66.
- Vymazal, J., Greenway M., Tonderski K., Brix H. and Mander U. (2006). Constructed wetlands for wastewater treatment. Wetlands and natural resource management, 69–96.
- Vymazal (Jan. 2005). Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. *Ecol. Eng.*, **25.5**, 478–490.
- Wang, X., Zhang Y. and Chen G. (2017). Constructed wetlands for wastewater treatment in cold climates: Challenges and opportunities. *Water*, **9(6)**, 437.
- Wenerick, W.R., Stevens S.E., Webster H.J., Stark L.R. and De Veau E. (1989). Tolerance of three wetland plant species to acid mine drainage: a greenhouse study. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea Michigan. *J. Environ. Qual.*, 801–807.
- Wolverton, B.C., Mc Donald R.C. and Duffer W.R. (1983). Microorganisms and higher plants for wastewater treatment. *J. Environ. Qual.*, **12(2)**, 236–242.
- Worall, P., Peberdy K.J. and Millett M.C. (1997). Constructed wetland and natural conservation. *Water Sci. Technol.*, **3**, 205–213.
- Woulds, C. and Ngwenya B.T. (2004). Geochemical processes governing the performance of a constructed wetland treating acid mine drainage, Central Scotland. *Appl. Geochem.*, **19(11)**, 1773–1783.
- Wu, H., Zhang J., Ngo H.H., Guo W., Hu Z., Liang S., Fan J. and Liu H. (2015). A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. *Bioresour Technol.*, 594–601.
- Wu, S., Kusch P., Brix H., Vymazal J. and Dong R. (2014). Development of constructed wetlands in performance intensifications for wastewater treatment: A nitrogen and organic matter targeted review. *Water Res.*, **57**, 40–55.
- Wu, S., Wallace S., Brix H., Kusch P., Kirui W.K., Masi F. and Dong R. (2015). Treatment of industrial effluents in constructed wetlands: Challenges, operational strategies and overall performance. *Environ. Poll.*, **192**, 245–262.
- Xinshan, S., Qin L. and Denghua Y. (2010). Nutrient removal by hybrid subsurface flow constructed wetlands for high concentration ammonia nitrogen wastewater. *Procedia Environ. Sci.*, **2**, 1461–1468.
- Ye, F. and Li Y. (2009). Enhancement of nitrogen removal in towers hybrid constructed wetland to treat domestic wastewater for small rural communities. *Ecol. Eng.*, **35(7)**, 1043–1050.
- Ye, Z.H., Baker A.J.M., Wong M.H. and Willis A.J. (1997). Zinc, Lead and Cadmium tolerance, uptake and accumulation by *Typha latifolia*. *New Phytol.*, **136**, 469–480.
- Ye, Z.H., Whiting S.N., Qian J.H., Lytle C.M., Lin Z.Q. and Terry N. (2001). Trace element removal from coal ash leachate by a 10 year old constructed wetland. *J. Environ. Qual.*, **30**, 1710–1719.
- Zhang, D.Q., Gersberg R.M., Zhu J., Hua T., Jinadasa K.B.S.N. and Tan S.K. (2012). Batch versus continuous feeding strategies for pharmaceutical removal by subsurface flow constructed wetland. *Environ. Pollut.*, **167**, 124–131.