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SUSTAINABLE WASTEWATER TREATMENT FOR LBOD USING CONSTRUCTED WETLANDS

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Abstract
Pakistan is an agricultural and growing industrial country in the developing world. The large volume of wastewater is disposed of through drainage systems in natural water bodies without any primary treatment. Pakistan's largest drainage project has been prepared to control wastewater and waterlogging. The Left Bank Outfall Drain (LBOD) Drainage System faces severe problems. The country is experiencing demographic, economic, and energy crises that pose severe barriers to capital investment in the wastewater treatment program. It is due to the complexity of the process, high energy consumption, lack of highly trained operators, and high capital and operational costs that have made it difficult to adopt conventional treatment systems for treating the wastewater of this large water body. This study aims to provide sustainable, low-cost, energy-efficient wastewater treatment solutions. To accomplish this objective, the application of constructed wetlands for the treatment of wastewater (LBOD) has been investigated. This work may be considered a tool for researchers and decision-makers to design and manage the parameters of constructed wetlands to treat wastewater in particular areas, including macrophyte species, media types, water level, hydraulic retention time, and hydraulic load rate (HLR).

INTRODUCTION

Water is a very vital element for the survival of life. Naturally, Pakistan is awarded ground and surface water resources. Unfortunately, over time, the growing rapid population, urbanization, and unsustainable water consumption practices in the industrial sectors and agricultural fields have significantly stressed the quantity and quality of the country's water resources [1]. Industrial sectors play a vital role in the economy and are considered the backbone of a nation; however, their effluents are damaging and degrading various ecological phenomena. Day to day, huge amounts of wastewater are released into the environment from agricultural, industrial, and municipal sources, causing serious ecological problems [2]. Another aspect is the negligible separation of industrial effluent from municipal wastewater. Both directly flow into open drains without treatment, becoming part of closer natural water bodies [3]. Open drains suffer from increased pollution loads caused by untreated wastewater discharge. This untreated wastewater highly affects the water quality of agricultural drains [4]. The Left Bank Outfall Drain (LBOD) system is one of the world's most significant drainage projects to dispose of 1,275 million acres of saline drainage water from Sanghar, Nawabshah, Mirpurkhas, and Badin components area (Command Area of 0.458 million Acres) to control the twin problem of salinity and waterlogging in Pakistan. Nowadays, this Drainage System is facing severe problems. The main sources of water contamination include the discharge of toxic sugar mill effluents, dumping of urban municipal wastewater, and seepage of fertilizers and pesticides from agriculture fields discharged into the main Drain without any treatment [5]. Such water pollution affects human health as well as biodiversity. Thus, the population in the downstream area, especially in southern Sindh, has been identified as having adverse health effects due to chemical and biological contamination of this water body [6]. Pakistan is currently facing demographic, economic, and energy crises that pose severe barriers to the spending of capital on water treatment. However, no prevalent attempt was undertaken by any department to characterize the true mechanism and concentrations of pollutants found in wastewater [2]. All types of wastewater are moving towards a single drain. Therefore, there is a tremendous requirement to choose the most cost-effective treatment system capable of treating wastewater [7]. Many wastewater treatment technologies have been implemented, and steps have been taken to enhance and maintain the quality of water, and also to provide simple and cost-efficient technologies accessible, particularly in rural areas. It is reported that recently constructed wetlands have become very efficient and cost-effective technology for wastewater treatment. The best option for many countries worldwide is constructed wetland technology, which is applied in biological, physical, and chemical treatment. Present research displays that COD (Chemical Oxygen Demand), BOD5 (Biological Oxygen Demand), TKN (Total Kjeldahl Nitrogen), TSS (Total suspended solids), etc., in constructed wetlands have been removed to a high level. The horizontal sub-surface flow (HSSF) CW was established with the local plant Hudiara drain in Pakistan to remove pollutants such as Turbidity, BOD, pH, Phosphates, and Nitrates [99]. This technology comprises various materials, like vegetation, gravel, and biochar. All of these combine to make the water treatment system effective, but certain variables, including location, weather conditions, and waste source, are matters. The type and suitable vegetation of constructed wetlands are extremely important. This paper reviews the constructed wetland system, which is the only option for the research area, and discusses the wetland efficiency and its mechanism, the plant species used in the system, and the plants' role in enhancing wetland system efficiency [1].

2.1 RESEARCH METHODOLOGY

2.2 Constructed Wetlands

The constructed wetland systems are entirely man-made wastewater treatment facilities, which are designed with different technology designs and natural wetland processes associated with soil hydrology, microbes, and plants. Therefore, constructed wetlands are engineered systems that have been developed and managed to use the natural methods in the treatment of wastewater with wetland vegetation, soils, and their related microbial components [8]. Synonyms used for "constructed" include "engineered," "man-made", or "artificial." [9].

2.3 Classification of constructed wetlands

Constructed wetlands may be classified by their Design criteria. Hydrology (open surface- and subsurface-flow); macrophytic kind of growth (emergent, floating-flowing, and freely floating); path flow (horizontal and vertical) (Fig. 1) in sub-surface wetlands are the key parameters of the Constructed Wetlands [10].

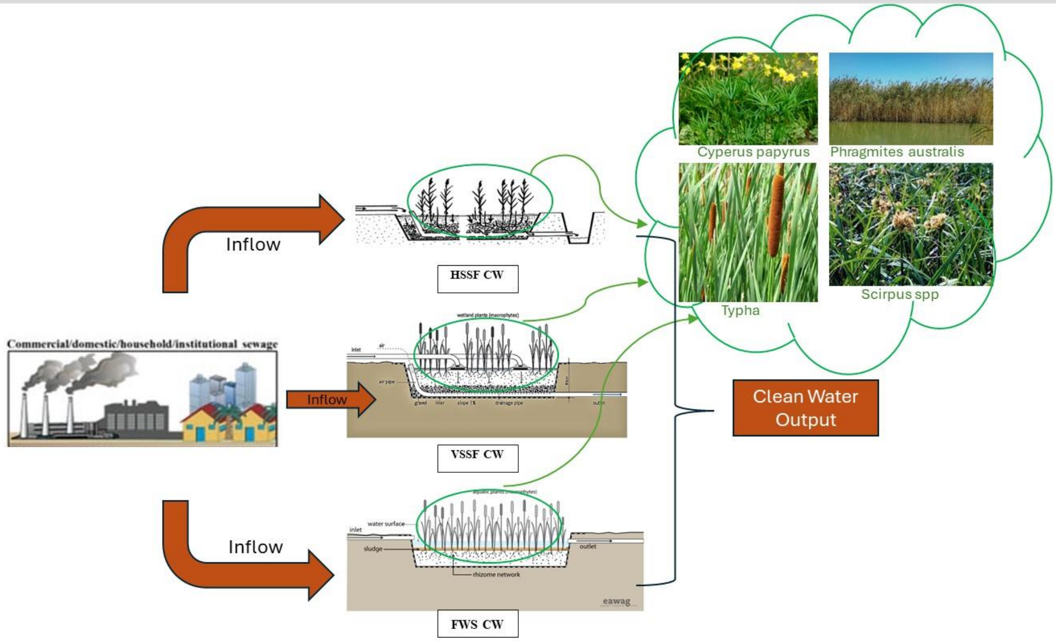

Figure 1. Wastewater Treatment in Constructed Wetlands

The various types of constructed wetlands can be combined to develop a hybrid system that uses them to achieve the unique goals of each system [11][9]. The following paragraphs provide further descriptions of constructed wetland types.

2.4 Horizontal Subsurface Flow Constructed Wetlands

Horizontal subsurface flow systems (HSSF) feature waterproof plastic tanks full of inert particle (e.g., gravel) material where emerging macrophytes (Phragmites australis, widely used even though in some countries it is considered an invasive weed) grow their roots, as illustrated schematically by Figure 2.

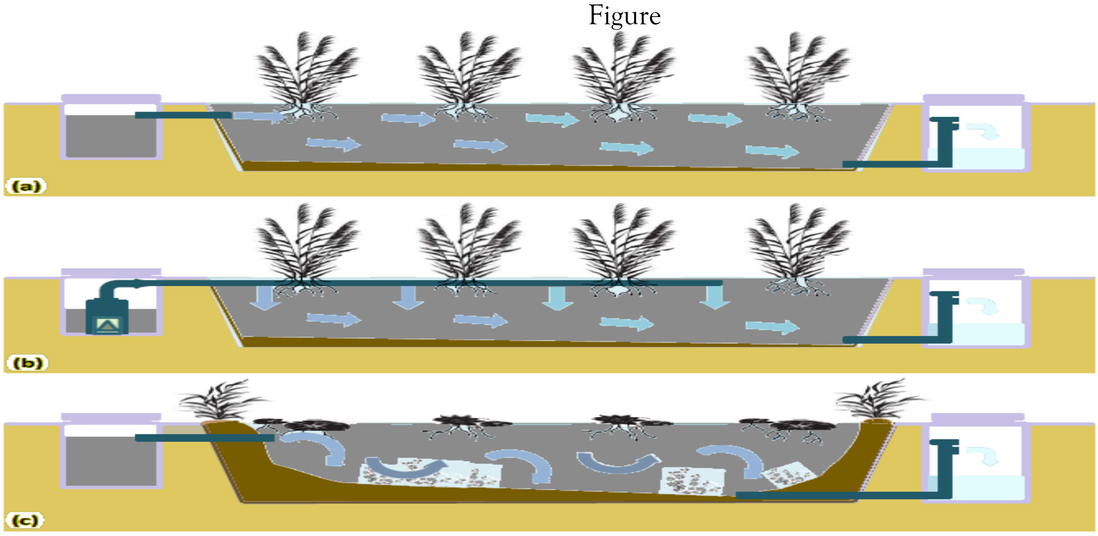

Figure 2. Illustration of roots

Under the inert material surface, the water flow is continuously maintained. This produces primarily anoxic and aerobic microsites at the roots of the plants that act as an oxygen delivery mechanism within the filter layer from the atmosphere. The method is highly robust, flexible, and efficient for the different wastewater types used for treatment and variations in pollutant contents due to its redox conditions[5]. In these systems, the wastewater passes through the inert material and is in contact with the rhizosphere macrophyte. The microbial activity works a degrading organic and nitrogen matter. Heavy metals adsorb to the inert material. Plant species help purify, first, by encouraging the fast growth of rhizospheric sand aerobic microbes, and second, by transferring atmospheric oxygen from the root system to the surrounding soil[12]. This improves wastewater oxidation and produces aerobic, anoxic, and anaerobic alternations. These factors correlate with the growth and near-complete loss of pathogens in certain families with different microorganisms because the rapid changes in dissolved oxygen are especially sensitive to each other. In winter conditions, the HSSF system is not tolerant to cold climates. In fact, in such weather conditions, system performance is always reduced. Maximize micro-organism functions in these systems to hold the affecting septic warm with insulation and, therefore, constant seasonal treatment efficiency. During winter, dead plants are often used for the protection of the filter bed as a natural insulation layer. The traditional HSSF-constructed wetlands can achieve high efficiencies in organic removal.

2.4 Vertical subsurface flow Constructed Wetlands

The vertical subsurface flow (VSSF) systems are geometrically designed and physically planned like to HSSF system (Figure 1). The key difference between HSSF and VSSF is the drainage transfer to the neutral medium. At the continuous intake and flow in HSSF systems in the horizontal direction, effluent is discontinuously entered into the tanks and flows vertically in VSSF Systems. The intermittent inlet is the condition of a “batch” reactor produced during filling and emptying cycles. At least in parallel, two tank systems running inside a separate flow are also needed so the period for the re-oxygenation of the bed can be controlled for wastewater intake at various frequencies and hydraulic load rates. This type of system's filling media consists of finer inert particles than the HSSF to allow for the most homogeneous distribution of the slow percolation of water on the whole surface of the bed 13[13], [14].VSSF systems use coarse sands, are suitable for hydraulic conductivity, help slow filtration, and give a ratio between volumes and surfaces greater than gravel in HSSF systems to facilitate biomass connection. The irregular wastewater supply, associated with a substratum in various particle sizes, helps to drain the medium alternately in situations of lack or excessive oxygen. Therefore, soil aeration, such as the removal of organic matter and nitrification, is gradually improved in aerobics processes. Since the conventional VSSF Constructed Wetlands for aerobic bacterial respiration provide an ideal environmental condition, they show better organic wastewater removal performance than conventional HSSF Constructed Wetlands. Nitrogen increases the oxygen excess by nitrification, which removes additional nitrogen or converts the main part into ammonia. In phosphorus light, the performance is much like that of HSSF CW. In the VSSF systems, common options for plants depending on the climate are Phragmites australis (reed), Echinochloa pyramidalis, and Typha sp. (cattails) [15].

2.5 Free Surface Water Constructed Wetlands

Continuous management of water volume over the surface region is carried out using natural and artificially waterproof tanks/channels having water depths of usually between 0.3 and 0.6 meters. The flow streams down the path to one or more sources that involve the inlet and every portion of the network. The areas defined by low water flow velocity and the existence of the installations standardize the flow by constructing several small channels that replicate the performance of a plug flow reactor. The goal of FWS design is to protect relations between wastewater and the base of an active biological system, to improve the system's efficient wastewater HRT, and to avoid the creation of direct flow [16]. These systems are used to remove pollutants to replicate natural wetland processes for pathogenic organisms, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, nutrients, heavy metals, and other micropollutants. Mainly, biological processes (surface conditions) or anoxic conditions (in-depth) remove the organic and nitrogen substances. Although sedimentation and/or plant filters, on the one hand, can remove suspended solids, on the other, they may be produced (for example, for the production of microalgae, plant tissue fragmentation, plant plankton production, and chemical precipitation formation). The phosphorus is removed in smaller amounts and can be absorbed, complex, and precipitated. In pathogens elimination, the FWS systems are extremely successful. This efficiency is, however, highly variable, primarily because of a complex combination of the physical, chemical, and biological processes that affect mechanisms for removal, such as sedimentation of the microorganism, UV emission in areas not covered by trees, and the presence of birds that contribute to feces [17]. Finally, by plant absorption, heavy metals can be removed, soil interactions and physicochemical, or complex formation and consequent precipitation [18]. The popular marsh species used in FWS systems are Eleocharis sp., Scirpus sp., Cyperus sp., Juncus sp., Phragmites australis, Glyceria maxima, Phalaris arundinacea, and Typha sp. A comparison of three different constructed Wetlands is in Table 1.

Table 1. ***Advantages and Disadvantages of Horizontal Subsurface Flow (HSSF), Vertical Subsurface Flow (VSSF), and Free Water Surface (FWS)***

	Advantages	Disadvantages
HSSF CWs	Long flow distances are possible; Gradients of nutrients can be established. Possible of nitrification and de nitrification Humic acid formation for removal of N and P Longer life cycle	High area required. Careful hydraulic calculation is needed for Optimum O_2 delivery. An equal supply of wastewater is complex.
VSSF CWs	Required small area. Good supply of oxygen – good nitrification Hydraulics are simple. High purification efficiency from the start	Flow distance is low. Low denitrification More technical requirements P-removal (saturation) performance losses
FWS CWs	Include the "green space" in a community. BOD, TSS, COD, organic materials, and metals were removed in a reasonable detention period. Removal of N and P for a much longer time	Area demand high Poor nitrification anoxic environment Anoxic environment—poor nitrification

2.6 Types of Wastewaters treated

The effective and suitable selection of wetlands for a given area depends on the type of wastewater being treated. Constructed wetlands have long been used mainly for municipal or domestic wastewater treatment. They are also used for other wastewaters, including irrigation and sewage.

2.6.1 Municipal Wastewater

The constructed HSSF wetlands are generally used in both the domestic and the tertiary treatment phases (in-house or household) and municipal (group of houses or community) wastewaters. Kadlec and Knight in 1996 reported typical composition of treated municipal wastewaters is COD = 500 mg $^{-1}$, BOD5 = 220 mg $^{-1}$, TSS = 220 mg $^{-1}$, NH4–N = 25 mg $^{-1}$, N org = 15 mg $^{-1}$, TKN = 40 mg $^{-1}$, NOx–N = 0 mg $^{-1}$, TP = 8 mg $^{-1}$[19]. It should be noted that HSSF Constructed Wetlands are able to treat wastewater at low organic concentrations successfully. For example, conventional wastewater treatment systems like activated sludge cannot be treated with low organic levels (usually less than 50–80 mg / L BOD5).

In all cases of study, including this work, it is potential in terms of removing load average performance in the treatment (RL) (kg/ha d) of HSSF constructed wetland for domestic and urban wastewater processing calculation: $CODR_L$ = 149, BOD_5R_L = 77.6, $TSSR_L$ = 83, TPR_L = 1.9 and TNR_L = 10.3 NH_4–NR_L = 5.3 [20], [21]. HSSF Constructed Wetlands are also successful in eliminating linear alkylbenzene [22], [23]. and pharmaceutical sulfones from wastewater by extracting toxins normally removed from urban wastewater [24].

2.6.2 Industrial Wastewaters

Constructed Wetlands are used for various types of industrial wastewater used to treat in Vymazal [20]. The following industries were categorized according to the type of industrial process: petrochemical and chemical industries, pulp and paper industries, textile and tanning industries, abattoirs, and meat-processing effluent food-processing industries. To treat of petrochemical industrial wastewater is targeted to remove various diesel range organics, BTEX hydrocarbons [25], [26], [27]. The Billingham, Teeside, United Kingdom, Air Products Chemical Works has developed in Europe and is known as one of the largest constructed wetlands (total surface area 49,000 m^2) [28]. Experiments have been conducted in Turkey, Portugal, Greece, and the United States about HSSF Constructed Wetlands are relatively new for the treatment of tannery wastewater [29], [30]. The use of HSSF Constructed Wetlands to treat textile wastewater in Germany[31] and Australia was carried out at the end of the 1980s and the beginning of the 90s[32]. Finlayson et al. reported the first experiments in the treatment of abattoir wastewater [33] from Australia. Gasiunas and Strusevi Altocius [34] and Gasiunas et al., [35] performed the most recent ones in Lithuania, which showed the results of an 1880 m2 HF CW for the processing of wastewater from meat production. White [36]For the first time, it was reported on HF CW use for food wastewater processing. HSSF Constructed Wetlands have recently been used to treat wastewater generated from cheese processing. It was reported by Mantovi et al., the wastewater from the Italian cheese manufacturers 'Parmigiano Reggiano' (400 m^2, 10.5 m^3 $^{d-1}$), or 'Grana Padano') (2700 m^2, 70 m^3 $^{d-1}$) was processed with HF Constructed Wetlands [37]. Both systems have a very high efficiency of treatment at 45 %, 62%, 94%, and 96%, respectively, for TSS, BOD5, COD, TKN, and TP were very efficient. Furthermore, the reduction in vegetable fats and the reduction in inflows to 1 and 2 mg L^{-1}, respectively, 59 mg L^{-1} (Parmigiano) and 167 mg L^{-1} (Grana Padano). High organic (up to 45.000 mg L^{-1} BOD_5) and solid, high acidity, and significant variations in the production of seasonal flow characterize wastewater in vineyards [38] [39]. The wastewater in the winery also has a small ratio between N / C and P / C. The high phenolic compounds and toxic nature of cork boiling wastewater are known. Total phenolic removal (TPh) was assessed for a 2.5-year monitoring period in an HSSF CW planted with Phragmites australis Gomes et al. Total TPh removal exceeded 69.1%, with a weight reduction of up to 0.5 g / m^2 / day respectively[40].

2.6.3 Agricultural Wastewaters

FWS Constructed Wetlands are commonly treated as a pretreatment step in the wastewaters of feedlot operations with a number of lagoons (settleable solids, solid digestion, and liquid portion treatment) [21], [41]. HSSF Constructed Wetlands are less widely used, but in scientific literature, many excellent examples can be found [35], [42], [43]. Table 2 shows an average performance for the treatment of wastewater from agro-processing in constructed wetlands. Considering all the cases included in this study, this average was calculated. Intensive pretreatment means that the input concentrations are much lower than in raw wastewater. Conversely, Rozena et al., [44] claimed that there is no one of the most efficient CW designs (HSSF, VSSF, FWS) for agricultural wastewater to prove the most efficient and successful designs for the hybrid wetland design.

Table 2. *Average Treatment Performance of HSSF Constructed Wetland Treating Agricultural Wastewater* (adapted from [35])

Concentration (mg/L)			Eff. (%)	n *	Loading (kg/ha d)			n *
	In	Out			In	Out	Rem	
BOD_5	464	183	68.2	43(19)	541	294	246	43(18)
COD	871	327	63	38(17)	1239	602	637	37(17)
TSS	516	180	76.9	56(26)	1430	779	651	54(23)
TN	116	57.5	51.3	31(13)	68	42	26	31(13)
NH_4-N	71.5	39.6	33.8	45(18)	74.6	19	55.6	45(18)
TP	19.8	8.5	54.3	44(18)	13.7	7	6.7	44(18)

A vegetated bed in = inflow. Out = final exit. Rem = load removed. * Number refers to the number of means per year in parentheses.

2.7 Stormwater Runoff

Agricultural and urban runoff are the two most common contaminated water polluting the quality of surface water [45] [46]. Many studies reported that urban stormwater pollutes surface water sources [47], [48]. Zhou et al. reported on the HSSF-constructed wetland used for farm stormwater and agriculture farm runoff treatment. The average total nitrogen (TN) inflow was approximately 22 mg L-1, with approximately 10% ammonia, 80% nitrate, and 10% organic nitrogen; depending on HRT, the removal range was 27% to 80%[20]. FWS Constructed Wetlands are mainly used for handling urban stormwater runoff. Walker et al. used the development of FWS for storms from a developed urban area in Queensland, Australia, during their two-year field experiment [49]. Some examples are also available for the use of HSSF and VSSF designs. For example, it was reported by Geary et al., [50] On that, HSSF CW was used to treat a 21 ha urban runoff from the catchment at Blue Haven, Australia. Scholz et al. [51]The treatment efficiency of macrophytic and granular filters with different adsorption capacities of VF wetland filters was assessed for 2 years. Campaigns for stormwater monitoring typically report pollutants by measurement of mean event (EMC) concentration, defined as[52].

$$\text{EMC} = \frac{\sum_{i=1}^{n} c_i V_i}{v} \qquad (1)$$

If V is the average runoff volume per event (L), V_i is the runoff volume over time I (L), Ci is the pollutant concentration over time I (mg / L), and n is the total number of samples for each case. With data from the EMC, the efficiency of pollutant removal can be evaluated. The efficiency ratio, CRE, measures the decrease in the concentration of contaminants in a given wetland system, and ER is described as the average pollutant EMCs for a particular wetland calculated for the duration of the storm events analyzed. They are defined as, respectively:

EMCin-EMCout
EMCin

CRE = ———————— (2)

no of events

μEMCout

$$ER = 1 \quad \mu EMCin \tag{3}$$

EMC measures on the system's inlet and outlet are the mean for EMCs at a CW inlet and outlet. Walker et al. calculated these two efficiencies. [49]

Considering some common urban runoff pollutants, as measured in 2 years (TSS, TP, TN, NO3–N, NH3-N, NOx – N), (Table 3).

Table 3. CREs and ERs of the FWS system treating urban runoff [49]

	TSS	TN	TP	NH_3–N	NO_3–N	NO_x–N
CRE ± std. dev. [%]	58 ± 29	7 ± 48	33 ± 33	45 ± 140	50 ± 33	49 ± 33 47
ER [%]	81	17	52	8	47	

3.1 RESULTS AND DISCUSSION

3.2 Wetland efficiency for wastewater treatment

The efficiency of wastewater treatment wetland systems is proven to be the best technology in the world. Dr Kathe Seidel performed the first experiment at the beginning of the 1950s in Germany; wastewater was treated using wetland plants.

The first complete policy was established by the end of the 1960s, and wetland systems have been in oper ation around the world since then [53]**.**Wetland technology is showing promising results with respect to pollutant removal [54]**.** It is the primary source of the advancement of this technology worldwide. In the United Kingdom, more than 1,000 wetland networks (CW) have been installed [55]. In the North-Eastern United States and East Canada, 25 full-sized Constructed Wetlands treat agricultural wastewater, with an average of good efficiency in removals of TSS, NH4 + -N, NO3—N, BOD5, TKN, and TP [44] [56]**.** Geographic conditions and weather in Russia really need careful consideration in terms of the accommodation possibilities of certain types of CW. Recently, in Russia, the use of xenobiotic removal constructed wetlands has been undertaken under climate conditions. It was both cost-effective and successful[57]. In Korea, many different types of wetland treatment systems have been developed in the last 10 years due to their low construction cost and simple operation and service. However, some problems were identified by [58] Systems are affected by winter's decreased process efficiency. The partial treatment should also be evaluated for 6-7 months a year [59].The technology was introduced quite late in Pak istan, from 2009 to 2010, "Pakistan's first community-managed constructed wetland" was launched by Sindhica Reforms Society (Sindhica), a small NGO with Indu's support for all programs WWF Pakistan and UN-HABITAT technical support for the South Asia Cities program for Water technical assistance.

S. Hayder et al. worked in Lahore city for wastewater treatment by using a constructed wetland. They analyzed the efficiency of disposal of the disposal system at different detention periods from 1 to 5 days. The results showed 90% removal of TSS, 75% removal of BOD, and 80% removal of COD for 5 days in detention. The mean effluent concentrations for TSS, BOD, and COD are 10 mg / L, 40 mg / L, and 68 mg / L, respectively. The detention was obtained for the duration of 5 days in compliance with the Pakistan effluent standards. For developing countries such as Pakistan, this is a low-cost and energy-efficient alternative [60]. The urban environment and ecosystem face two major challenges in Egypt: water scarcity and wastewater management. Egypt is known as an arid country. Reuse of wastewater must be encouraged since it is documented as safe and financially feasible that wastewater is reused.

There are many approaches available for treating was tewater, but the most effective way of treating using wetlands [61]. The University Putra Malaysia Faculty of Engineering in Malaysia is trying to deal with water treatment problems. A study by S. Katayon shows that 27-96 percent of TSS, 56-77%, NH4 +, 50-88% of COD, 20-88% of TP, and 99% of total coliform percentages were removed by the constructed wetlands[62]. A CW system based on the lab model in Kerala, India, which includes the plant 'Reed', has achieved significant results in the efficiency of removal of domestic wastewater [63]. The main objective in Ireland was to identify 52 wetlands in 17 city authorities with the most efficient constructed wetland types. Some constructed sites managed to reach long or commonly zero effluent dump times, and no waterborne pollution was passed through these cycles to their receptors [64]. In addition, this technology has very few disadvantages. Constructed wetlands take a larger land area than other technologies, depending on the design. The population of mosquitoes is increasing due to wetlands, which can be the source of diseases such as malaria or other mosquito-borne diseases. The anaerobic decomposition of organic matter creates about one-quarter of Earth's atmospheric methane. Nutrients are sometimes modified by wetland bacteria into harmless forms all year round. Constructed wetlands cannot be treated with highly toxic modern wastewater unless pretreated in special facilities. In the constructed wetlands, bacteria and plants release their nutrients to degrade in the system in cold winter climates. It is not well known that the biological processes of a constructed wetland. Residual contaminants can adversely affect wildlife in the reserve [65] [66] [67]Multiple studies show that wetlands are an efficient and cost-effective method of removing water contaminants. Finally, some recent studies around the world have concluded that constructed wetland technology is very cost-effective and efficient, and best at removing pollutants up to 99%.

Table 4. Removal percentage of pollutants by wetlands

S.No.	COD	BOD_5	TN	TKN	TSS	TDS	TP	References
1	99%			94%	98%		83%	[44]
2	86.6	83.7%		36.66%		87.36%		[68]
3			69.96%				82.4%	[69]
4					83%	58%		[70]
5	97.2%		90.6%					[71]
6	75%		75%				55%	[72]
7			67%					[73]
8	74.6-76.6%		60.1-84.7%				49.3-70.7%	[74]
9		87.81%			86.10%	67.27%		[75]
10	89.2%		90.0%				50.3%	[45]
11	91%							[76]
12			60% ± 12%				77% ± 4%	[77]
13	95.6%		85.8%					[78]
14	91.3%		58.3%				79.5%	[79]
15					85%		68%	[80]
16	83-88%	90-95%			89-93%			[81]
17	66%		79%					[82]
18	91 ± 7%	95 ± 5%	70 ± 10%				90 ± 6%	[83]
19		81%		75%	83%		64%	[84]
20	69%		69%					[78]
21			43%	38%				[53]
22	65%		43%					[85]
23	68.1%			78.25%	86.5%		64.85%	[86]
24			71%					[87]

3.3 Influencing Factors on Treatment Effectiveness

CWs are engineered designed systems that mimic the natural filtration process of water treatment. The condition and magnitude of various factors that control the efficiency and performance of CW are:

3.3.1Hydraulic Loading Rate (HLR)

In wetland operation, HLR is a critical parameter. HLR reflects how much wastewater is introduced into the wetland and how rapidly it moves through the system. When the HLR was increased from 0.75 $\frac{m^3}{m^2.d}$ to 1.5 $\frac{m^3}{m^2.d}$, a significant high removal efficiency of suspended solids and organic carbons was seen [95]. HLR significantly influences the function and composition of microbial communities in CWs, and the effects of rhizosphere on microbial communities were reduced by increasing HLR [95]. At low HLR, the removal efficiencies of COD, Total phosphorus (TP), - N, NO_2^-, and NH_4^+-N are high in CWs. However, their removal efficiencies were decreased when the HLR was increased [96]. The relationship between HLR and the efficiency of constructed wetlands in nutrient removal is of significant interest [97]. CW environments, like microbial communities' regulation, wetland moisture, oxygen dissolution, and plant growth, are greatly influenced by wastewater flow or HLR [98].

3.3.2 Hydraulic retention time (HRT)

It is the duration of time during which wastewater stays in a wetland. During this period, various chemical, biological, and physical reactions take place. Higher HRT results in better efficiency of wetlands. More microbial colonies establish and adapt to inflowing wastewater when HRT is longer. An HRT of 8 days seemed acceptable to remove the organic matter, P-PO_4^{3-}, and Total Kjeldhal nitrogen (TKN) from pilot-scale HSSF CW [100]. Over 90% of nutrients, TKN, NO3-N, and 100% NH4-N, were eliminated when the HRT was set to 4 days in subsurface flow (SSF) CW [101]. For the removal of COD and BOD, a 6-day HRT was found adequate in HSSF CW. Higher inflow or loading results in higher effluent concentration, which results in lower removal efficiencies. When the HRT is increased, the removal efficiency of all parameters increases [102].

3.3.4Wetland Design

The design of wetlands is a crucial step that has a greater impact on removal accuracy. The surface area and volume (length, width, and depth), hydraulic configuration (HSSF, VSSF, and FWS), and substrate selection (gravel, sand, and soil) can optimize the wetland's performance. Substrate permits the successful movement of wastewater in CW. Poor permeability of the substrate results in decreased performance of the system and clogging of the system [105]. Some frequently used substrates are gravel, shell, sand, fly ash, clay, marble, calcite, slag, bentonite, limestone, zeolite, and lightweight aggregates [106] [107]. The media types and vegetation species are considered to be the main biological factors that impact removal performance [104]. A cylindrical, pilot scale vertical flow Wetland was constructed. The porous media (i.e., bauxite and zeolite) with 2 types of vegetation cattails and reeds were used. The results showed quite better removal accuracy for TP, TKN, NH_4^+—N, Nitrogen, COD, and BOD_5 [103].

Water depth is important in determining the plant type to be used in CW. In a study [108], the water depths of 0.27 m and 0.5 m were compared, and it was observed that the pollutant removal efficiencies vary with depth. The recommended values for essential parameters in CWs design are listed in Table 5.

Table 5. Recommendations for design parameters of CWs for wastewater treatment. Source: modified from: [109]

Parameter	Type of CWs		
	HSSF CWs	VSSF CWs	FWS CWs
HRT (days)	2-7	3-10	3-10
HLR (m/day)	0.1-0.5	0.05-0.3	0.05-0.3
Water Depth (m)	0.5-1	0.5-1.5	0.3-0.6

Length-to-width ratio	2:1 to 4:1	1:1 to 2:1	2:1 to 4:1
Media	Gravel or coarse sand as primary media		
Vegetation	Native species are desirable.		

3.3.5 Removal mechanisms and wastewater constituents

Table 6. Removal mechanisms and wastewater constituents. Source: modified from: [88] [89].

Removal mechanisms and wastewater constituents	
Wastewater constituents	**Removal mechanisms**
Heavy metals	Sedimentation, adsorption, plant uptake, chemical precipitation, infiltration
Bacteria/pathogens	Sedimentation, natural die-off
Synthetic organics	Sedimentation, adsorption, oxidation, volatilization, infiltration
Hydrocarbons	Bio-filtration, microbial decomposition, oxidation, plant uptake metabolism
Total phosphorus	Matrix sorption, plant uptake, sedimentation, bio-filtration
Nitrate	Denitrification
Nitrite	Denitrification
Ammonia	Nitrification
Biological oxygen demand	Sedimentation, bio-filtration,
Chemical oxygen demand	Sedimentation, bio-filtration, oxidation
Suspended solids	Sedimentation, filtration
Soluble organics	Aerobic microbial degradation, anaerobic microbial degradation
Total nitrogen	Ammonification followed by microbial nitrification, denitrification, plant uptake, matrix adsorption, ammonia volatilization

3.4 Wetlands Efficiency vegetation

Wetland vegetation is an essential component of wetlands that are involved in the wastewater treatment processes. Efficiency increases for the removal of common pollutants with different suitable vegetation; much research around the world has shown. [90]. The morphometry of construction wetlands does not resemble natural wetlands; this explains why the composition of the vegetation is different. Plants provide a substrate, and the most important wastewater contaminant processors are micro-organisms with a carbon source. There is a range of processes in which heavy metals can be absorbed by leaves and roots of plants, with pollutants: (i) phytoextraction. (ii) Rhizo filtration (root-contaminated liquid absorption and precipitation process). It is also useful for degrading organic compounds. (iii) Phyto-stabilization: The mechanism through which plants tolerate metals reduces their mobility into air or groundwater, in particular, chlorinated compounds. (iv) Phyto-stimulation: System where roots contribute to the biodegradation of products, such as Benzene, polyaromatic as petrochemical hydrocarbons, etc. (v) Phytovolatilization: The mechanism through which heavy metals and other chemical agents are collected and released into the environment by transpiration. (vi) Phyto-decomposition: Processes for decomposing and reducing the toxicity at a significant level of both terrestrial and aquatic plants to organic compounds [91]. Sieben et al. (2016 studied vegetation classifications and gave an overview of various types of wetland habitats in South African semi-arid zones. There are two forms of resilience (altered hydrology and physical human disturbance). From this, it was concluded that hydric species are not as hydrologically adaptable as terrestrial species [92]. Pretorius and Brown studied different wetland types during the planting of main vegetative carriers in South Africa. This research indicated that the composition of vegetation is different for wetlands, so better outcomes should be analyzed individually. The immoderate usage of such wetlands can, therefore, boost their deterioration as broad indigenous vegetation as urban design and building fiber may be used for construction in wetlands.

Vegetation plays a key role in removing pollutants from wetland wastewater because the type of vegetation s, therefore, specifically affects the reduction efficiency of all wetland types [93] [94]. Leung et al. (2016) studied mangrove plants' efficiency in treating wastewater of Constructed Wetlands (Aegiceras corniculatum Bruguiera gymnorrhiza) and non-mangrove plants (Canna indica, Acorus calamus, and Phragmites australis). The findings of comparisons showed that Mangrove Constructed Wetlands plant a. In treating toxic wastes, corniculatum provided higher values than non-mangrove Constructed Wetlands. However, a water jacinth plant also removes nutrients from wastewater efficiently [69]. In Eastern Africa, Moges et al, (2016) developed the plant-based biological integrity index of 122 plant species of 37 families, aiming to provide an effective tool for assessing the long-term conditions of natural wetlands and, therefore, for facilitating wetlands management. In the United States, Constructed Wetlands are an immense problem due to erosion in this semi-arid country, which is destroying playa wetlands. Therefore, Haukos et al.. (2015) assessed the role of playa-wetland vegetation in removing nutrients, metals, and dissolved/suspended solids from the runoff. The findings suggest that vegetative buffers removed approximately 58% TDS, 83% TSS, 78% N, and 70% P. Vegetation buffers are used as an economical method for handling playa wetlands, highlighting the effect of seasonal change on contaminant removal. The study reported that the efficiency of three plants, Thalia, dealbata, and Lythrum salicarium, was performed in the removal from municipal storm-water wastewater of total nitrogen (69.96 percent) and total phosphorus (82.4 percent). Finally, It is concluded that the best plant-growing species were selected for Constructed Wetlands [70].

4.Conclusion

The overall conclusion of this review suggested that constructed wetlands are viable options for LBOD wastewater treatment in Pakistan. It becomes the best alternative to remove liquid pollutants, including microbial bacteria, inorganic matter, and microbial trace materials, and it handles water biologically, chemically, and physically. It is not a modern technology because several countries worldwide continue to use constructed wetlands even before they were used in Pakistan at different project sites to treat wastewater by WWF Pakistan. The previously published data have shown that the removal concentrations were constantly high for Suspended solids, nitrite and nitrate, ammonia/ammonium, Total Phosphorous (TP), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD), which are the primary contaminants of LBOD wastewater. It can, therefore, be concluded that constructed wetland treatment technology for a particular location is an economically viable, environmentally friendly, and technically very feasible option for the Pakistan LBOD Drain project. Removing organic products and suspended solids from all constructed wetlands is very effective. In contrast, removing nitrogen is less but could be improved by combining various constructed wetlands. Phosphorus removal is generally low if special media have high sorption capacity. The requirements of the constructed wetlands for minimal input energy are, therefore, significantly lower than those of traditional treatment systems for their operation and maintenance. Furthermore, future research is required to solve the issues in constructing the wetland system in combination with various advanced techniques for better water treatment. The feasibility and effectiveness of suitable treatment methods must be explained, and the resulting material should be disposed of safely after treatment. There is still a gap, so it is necessary to investigate the constructed wetland and suitable vegetation options for LBOD wastewater with its suitable area for constructing the constructed wetland.

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