**View of review of wastewater treatment using constructed wetland systems (CWS)**

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**Abstract**

Wetlands are marshy ecosystems that are saturated at certain times of the year and have a wide range of aquatic plant life. However, during the past several decades, it has become clear that the deliberate use of wetlands has been well studied and implemented in a controlled fashion to meet wastewater treatment and water quality objectives. As an alternative to conventional wastewater treatment methods, constructed wetland systems (CWS) have been proven to be effective, cost-effective, and environmentally friendly.Pollutants are removed in wetland systems by physical, chemical, and biological processes associated with the plant, sediment, and microbial communities. Over the past few decades, numerous studies have been undertaken to measure how well wetlands treat wastewater. This information has been utilized to improve treatment efficiency through design and operating tactics. This study provides a comprehensive overview of many types of constructed wetlands that may be utilized to treat wastewater.

**Keywords:**Constructed wetland, wastewater treatment, wastewater reuse, subsurface flow.

**عرض مراجعة معالجة مياه الصرف الصحي باستخدام أنظمة الأراضي الرطبة المبنية**

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**الخلاصة:**

الأراضي الرطبة هي أنظمة بيئية تكون مشبعة في أوقات معينة من السنة ولديها مجموعة واسعة من الحياة النباتية المائية. ومع ذلك ، خلال العقود العديدة الماضية ، أصبح من الواضح أن الاستخدام المتعمد للأراضي الرطبة قد تمت دراسته جيدًا وتنفيذه بطريقة مضبوطة لتلبية أهداف معالجة مياه الصرف الصحي وجودة المياه. كبديل لطرق معالجة مياه الصرف الصحي التقليدية ، ثبت أنها أنظمة فعالة ، وفعالة من حيث التكلفة ، وصديقة للبيئة ، حيث تتم إزالة الملوثات في أنظمة الأراضي الرطبة عن طريق العمليات الفيزيائية والكيميائية والبيولوجية المرتبطة بالمصنع والرواسب، والمجتمعات الميكروبية. على مدى العقود القليلة الماضية ، تم إجراء العديد من الدراسات لقياس مدى جودة معالجة الأراضي الرطبة لمياه الصرف الصحي. تم استخدام هذه المعلومات لتحسين كفاءة العلاج من خلال أساليب التصميم والتشغيل. تقدم هذه الدراسة نظرة عامة وشاملة للعديد من أنواع الأراضي الرطبة المبنية التي يمكن استخدامها لمعالجة مياه الصرف الصحي.

**الكلمات المفتاحية:** الأراضي الرطبة المبنية، معالجة مياه الصرف الصحي، إعادة استخدام مياه الصرف الصحي، التدفق تحت السطحي.

**1. Introduction**

Reusing wastewater for purposes that don't call for high-quality water is gaining popularity across the world as a method to free up limited potable resources and reduce effluent discharges into recipient rivers. The usage of fresh water must be reduced in all areas of consumption, alternative water resources must be substituted and water use efficiency must be optimized by reusing possibilities. Rainwater and grey water are two examples of alternative supplies. Wastewater recycling is one potential source ofnew water. Water conservation is a top priority for researchers all over the world.Reusing wastewater in an economically sensible way is one of the finest ways to recycle water. Residential or non-industrial wastewater, such as that produced by the toilet, kitchen sink, or shower, is referred to as "wastewater." Laundry, dishes, shower, and sink. Water reuse is becoming more common in developing countries because of fast industrialization and growth.The choice of treatment procedure, such as chemical or biological, is dependent on the properties of the wastewater, the environment, and the economy. Before deciding on the best process, take the environment into account. Engineered systems created and built to leverage natural processes are used in wastewater treatment facilities. These systems imitate natural wetland systems for the removal of contaminants from wastewater effluents by using the plants, soils, and bacteria of wetlands (EPA, 1993). Constructed wetland systems (CWS) filter, settle and degrade wastewater in a simulated lined marsh. Wetland systems that have been built have demonstrated encouraging outcomes internationally. The effluent generated by a well-designed wetland system should have less than 30 mg/L BOD, less than 25 mg/L total suspended particles, and less than 10,000 fecal coliform bacteria cfu/100 milliliters [13].

Marsh vegetation was not initially investigated as a viable method of wastewater treatment until K. Siedel's early 1950s studies at Germany's Max Planck Institute in Plon. She conducted several studies on the utilization of wetland vegetation for the treatment of different types of wastewater, including dairy wastewater and animal wastewater. To enhance rural and decentralized wastewater treatment systems, which were either septic tanks or lakes with insufficient treatment procedures, macrophytes were initially studied in wastewater and sludge from diverse sources in the early 1960s. Siedel came up with the term "hydrobotanical approach" to describe this early technique [38]. In the 1970s and 1980s, treating home and municipal sewage was nearly the exclusive application of construction wetlands. Built wetlands have been used to treat a broad variety of waste streams, including mine drainage, landfill leachate, storm water runoff, food processing waste, industrial waste, and sludge dewatering, since the 1990s. The several types of artificial wetlands used to treat waste water are covered in this paper.

**2. Constructed wetland**

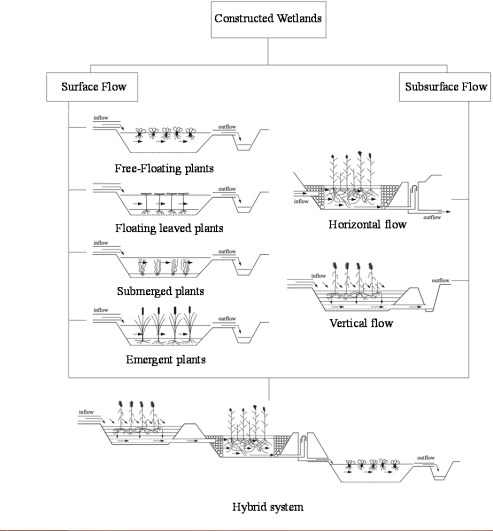
Secondary and tertiary treatment of wastewater and stormwater using constructed wetlands is becoming increasingly common. By carefully building and maintaining their effluents, they may meet the stringent standards set for water reclamation. It is possible to partially replenish nutrients by harvesting aquatic vegetation or combining wastewater treatment with aquaculture. It's important to remember that the benefits of man-made wetlands extend well beyond providing a haven for wildlife and a place to have fun. To provide new or restored habitat for native and migratory wildlife, treat anthropogenic waste, stormwater runoff, or sewage runoff, reclaim the land after mining, refineries, or other ecological disturbances, or fulfill mitigation obligations for natural areas lost to development are all examples of the types of uses for artificial wetlands. Ecosystems in wetland areas can act as carbon sinks, carbon sources, or a combination of the two [26]. Wetlands, both natural and constructed (CWS), have been widely employed to improve water quality for this reason [6].

Using natural wetland processes associated with wetland hydrology; soils; bacteria and plants; and a wide variety of technological designs, built wetlands systems are human-created wetlands for wastewater treatment. The natural processes involving wetland plants, soil, and the microbial assemblages that they sustain are utilized in CWS to aid in the treatment of wastewater. The adjective "constructed" can also mean "man-made," "engineered," or "artificial" [39]. CWs are used for three main reasons: to degrade or sorb wastewater for better quality, to store stormwater runoff to lower flood danger, and to recycle nutrients [15, 2, and 12].

But wetland values include recreational places and adequate data for research and teaching. The type of flow in manmade wetlands is directly influenced by local ordinances and bylaws. When surface flow is prohibited by local regulations, designers are forced to opt for vertical flow [27].

**3. Kinds of wastewater treatment built wetlands**

The three most important criteria for classifying artificial wetlands are hydrology “water surface flow and subsurface flow”,macrophyte growth type “emergent, submerged, free-floating, and floating-leaved plants”, and flow route “horizontal and vertical” as illustrated in Figure (1) [39]. To benefit from the unique qualities of each system, it is feasible to combine several kinds of CWs (hybrid or mixed systems). For instance, in the 1990s and 2000s, a new design technique was used to make sure that ammonia and total nitrogen (N) removal was more effective [40].

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**“**Figure 1: types of constructed wetlands for wastewater treatment”.

**3. 1. Wetlands with the surface flow (SF)**

Open sea level Constructed wetlands (CWs) are artificial wetlands that have surface flow (SF) and have areas of open water with floating, submerged, and emergent vegetation [22]. Even in the coldest climates, such as the far north, SF CWs may be utilized effectively [25]. Plant stalks and litter, slow flow velocity, and shallow water depth all contribute to better water filtration, particularly in long, narrow channels[10]. Stormwater runoff, mine drainage fluids, and tertiary treatment of municipal wastewater are the most typical uses for SF CWs [22].

**3. 2. Subsurface-flowing constructed wetland**

Horizontal subsurface flow constructed wetlands (HSF CWs) take in wastewater from an inlet, then gently convey it through a porous medium beneath the surface of a bed planted with emergent vegetation to the outlet, where it is collected before leaving via a water level control structure [42]. The wastewater flows through a series of zones that are alternately oxygenated (by oxygen), depleted (by oxygen), and anaerobically oxidized (by carbon dioxide). The bulk of the bed is anaerobic due to the beds being constantly soaked. When oxygen is leaked into the substrate via roots and rhizomes, the aerobic zones form [6].To avoid seepage and guarantee controlled outflow, HSSF CWs are frequently lined. While numerous other uses have been documented in the literature, HSF CWs are frequently employed for the secondary treatment of municipal wastewater [41]. Because these systems cannot transfer enough oxygen for aerobic breakdown, anaerobic activities are crucial in HSSF CWs [41].Some HSSF CWs can function in colder temperatures than SF systems because they can insulate the bed's surface [25].

Vertical subsurface flow constructed wetlands (VSF CWs) have a gravel base that is covered with sand and macrophytes before being flooded. Water flows into VSF CWs in enormous, intermittent bursts, which saturate the surface of the bed before percolating down and being collected at the bottom. When the bed is drained, it can be refilled with fresh air. Because of this, VSF CWs produce a more nitrified (high NO3 -) effluent [8,9].As a result, denitrification cannot be completed in VSF CWs, resulting in the release of gaseous nitrogen into the atmosphere. With tidal (fill and drain) flow systems, the effluent is in closer proximity to the microorganisms growing on the medium. This has a major bearing on the cleansing process [40].

**3. 3. Hybrid Constructed Wetlands**

It has been shown that using many CW kinds together increases their efficiency at removing nitrogen. The design consists of a series of two or three horizontal flow (HF) beds positioned after a series of parallel vertical flow (VF) beds “VSF-HSF system”. Both the VSF and HSF wetlands had their organic and suspended solids removed, but the HSF wetland has also undergone gentrification and has had much more of both removed. The HSF-VSF system is another option. As a prelude to gentrification, a substantial HSF bed is first installed. Additional removal of organics and suspended particles, as well as nitrification of ammonia into nitrate, are accomplished using a small intermittently filled VF bed. The VF bed nitrified effluent must berecycled to a sedimentation tank, however, to remove the greatest amount of total N [40]. Both VSF-HSF and HSF-VSF can be used in conjunction. Even though CWs represent the most prevalent type of hybrid system, any type of CWs can be mixed to boost treatment efficiency [39].

**4. Parts of Constructed wetland systems**

Liner, Distribution Media, Vegetation, and underdrainsystems are the four components of constructed wetland systems.

Due to the lining, wastewater is contained and cannot seep into the earth. Although several materials are suitable for making the liner, Polyvinylchloride (PVC) is the most popular and dependable option. Clay liners should be avoided since they are prone to cracking, allowing contaminated wastewater to seep into the ground. Drainfeild rock with a diameter of 0.75 to 2.5 inches is the distribution medium at the intake. The wastewater can be disseminated uniformly across the wetland's width using the first element of the distribution system. Using gravity and pressure distribution, effluent may be distributed uniformly throughout the system [13].

CWs with free-floating macrophysics may contain both large plants with well-developed buried roots, such as water hyacinths, cattails, and bulrushes, and tiny surface-floating plants with little to no roots, such as duckweed [19]. The effectiveness of water hyacinths in treating wastewater has been demonstrated [31, 32]. As a result of the weed's extensive root system, microbes have a lot of surface area to work with, which increases the likelihood of organic matter being decomposed. Absorption by plants is the primary mechanism by which wastewater treatment systems including water hyacinth plants remove nutrients [31].

**5. General design criteria for constructing wetland**

For surface flow, a basin's slope of 3:5 or less is ideal (SF). It's important to have a waterproof base for the CW. Two or three days are recommended for the hydraulic retention period. Two measures of influent quality are total suspended solids (TSS) and biological oxygen demand (BOD) (TSS). Daily loading rates of BOD and TSS might be between 45 and 50 kilograms per hectare (kg/ha). On the other hand, 7-16 g/m2 per day for BOD and 20 g/m2 per day for TSS are ideal for subsurface flow. Minimum and maximum lengths of 15 m and 61 m are proposed.There are both transverse and longitudinal differences in hydraulic conductivity. The subsurface flow of CW varies between 1400 and 2800 m/day, according to one research, while another recommends 1000 m/day for the first 30% of the length. However, it is expected that, as systems age, the soil pores would get clogged, thereby resulting in a less porous system. Previous research has shown that the hydraulic conductivity in the output zone of aging systems can vary anywhere from 30 to 107 m/d [11, 5].

Removal of trees and grass, construction of a fence around the site to minimize compaction, and the use of inorganic fine-grained soil for backfilling are some of the fundamental considerations that should be made when developing CWs for a single family. For a 30 L influent or a 5-day detention time, CWs of 1 m2 in size is recommended.It should be made sure that the length is twice as wide as the width. Two people can be accommodated in each bedroom, resulting in an estimated 210 L of wastewater per individual each day. As a result, the area of CWs for a two-bedroom home “should be 28 m2, with dimensions of 7.5 m 3.75 m” [29].The wastewater from an eight-person, two-family house was treated with a vertical flow centrifugal filter (CW) with an area of 24.4" x 3" x 1.5" of surface area and a depth of 1.3". The system includes two settling tanks, an effluent tank, a zeolite tank, and a pump that feeds the CW with 150 liters of wastewater every three hours. The system was built to treat 150 liters of water per capita each day. Porous medium included coarse gravel “20–40 mm diameter” and fine gravel “2–10 mm diameter”. It was used to remove ammonia and phosphorus from the water supply. BOD, COD, TKN, ammonia, OP, and TP removal efficiencies were 96.4 percent, 94.4 percent, 90.8 percent, 92.8 percent, and 61.6 percent, respectively [18].HSF CW was previously utilized in a study with a single household of four individuals. There were two settling tanks, CW (ten feet long by 2.5 feet wide), and a tank of zeolite (1.6 feet long by 1.25 feet wide). According to the results, the average BOD concentrations were 120–150 mg/L, hydraulic residence times were seven days, and the flow rate was six meters per second. [17] The BOD effluent content was approximately 30 mg/L, which indicates an 87 percent elimination of the BOD [17].Before CWs can be installed, sediments and muck must be removed using septic tanks. The CWs can be loaded using a pump, however, it is best to avoid using gravity if possible to avoid overdosing (gravity inflow)[35].

There should be no more than 600 mm of water in the cells for the oxygen content to be sufficient for microbial metabolism. Avoiding leakage from the CWs can be accomplished using PVC, HDPE, or PPE of 1 mm [35, 40, and 29]. It is important to take precautions during insulating to prevent the liner from being pierced. When filling the CWs, gravel of varying sizes should be utilized. The entrances and exits of most CWs may be used to classify the kind of gravel that lies in the middle of the channel, as well as the gravel that lies on its upper and lower sides. Gravel sizes should range from 38 to 76 millimeters at the inlet and outflow (the boundaries), 12.7 to 25.4 millimeters in the middle layer's bottom, and 9.5 to 12.7 millimeters in the top layer's middle. The intake and outflow of a CW should be well-planned for optimal performance [35, 40, and 29].

Calculating the amount of water in a system can be done using the following equation:

“Qin - Qout + P - ET = dv/dt” ---------------------- (1)

“Where Qin = influent wastewater flow” (m3/s);

“Qout = effluent wastewater flow” (m3/s);

“P= precipitation” (m3/s);

“ET= evapotranspiration” (m3/s);

“V= volume of water” (m3);

“t = time”.

Because of the potential for blockage in the subsurface flow system, the intake for vertical flow (VF) must be filtered [14]. High sorption sites, like charcoal and clay, may be present in the filtering system and encourage the development of pathogens [30]. Therefore, the quality of the effluent may be improved and infections managed by selecting elements like gravel and slag that impede the growth of bacteria. However, the temperature has a major impact on the biological treatment of wastewater. This means that temperature is an essential consideration while developing CWs. Since degradation may be slowed by low temperatures, the retention duration in the design may need to be increased. To give you an idea, a detention duration of 11 days is required for an influent of 112 kg/ha at 5 \_C, but at higher summer temperatures, this drops to just 5 days [30]. The retention time may be modified by changing either the cell density or the water level.

Horizontal flow (HF) may be modeled using Darcy's Law.

"q = k. i. A" -------------------------- (2)

"where: q = average daily flow rate (m3/d)";

"k = hydraulic conductivity (m/d)";

"i = hydraulic gradient (m/m)";

"A = cross sectional area (m2)".

There should be minimal filling and cutting in the HF CW system, and it should rely on gravity flow [1]. Additionally, the design should be carried out according to the organic and hydraulic design criteria; nevertheless, other metrics should be assessed, such as pathogen reduction and nutrient removal. Depending on the nature of CW, the water flow in HF should be managed to keep water levels above the bed's surface [40, 4, 3]. While the bottom layers of the HF should be built to assist anaerobic degradation, the top surface layer should encourage aerobic degradation. Table [1] details the building, usage, and maintenance of several different types of CW[1].

Table [1]: Information about the design, operation, and maintenanceof different types of CWs.

|  |  |  |  |
| --- | --- | --- | --- |
| "Type of  Constructed Wetland" | "Design" | "Operation" | **"**Maintenance" |
| "Surface Flow (SF)" | Simple, reliant on a sizable amount of land, and on gravity flow. | Low cost, easy operation, high evapotranspiration, low temperature  bacteria | Temperature flocculation, odor, and insect issues are severe. |
| "Horizontal Subsurface flow (HSF)" | Complex, requiring sedimentation tank, pumps | More sorption sites than SF, but more expensive to run; flow must be uniform with minimal solid content; no evaporation or condensation to worry about. | Higher resistance to subzero temperatures; less odor production; fewer insect problems. Issues with clogging and increased upkeep |
| "Vertical Subsurface flow (VSF)" | Intricate requires less space than SSF, sedimentation pond, and pumps | More sorption sites than SF, but more expensive to run; flow must be uniform with minimal solid content; no evaporation or condensation to worry about. | Higher resistance to subzero temperatures; less odor production; fewer insect problems. Issues with clogging and increased upkeep |

**6. Literaturereview on the performance of constructing wetland**

Efficient CWs were the subject of study by Canter et al., 1982. It would appear that in many cases, the demands of poor countries may be met by wastewater stabilization ponds. Depending on the loading rate (in kilograms of biological oxygen demand [BOD] per acre per day), removal efficiencies of 75–90%, 30–50%, 20–60%, and 60–99% have been observed in the Tropics[7].

Both Watson et al. (1989) and Kadlec and Knight (2005) highlight the benefits of wetland technology for wastewater treatment (1996). Chemicals or substantial amounts of fossil fuel are unnecessary. In addition to water supply, public recreation, wildlife protection, and scientific study, wetlands may provide several other advantages when used for wastewater treatment. These include fisheries, biomass production, and seasonal agriculture. In underdeveloped nations, wetland systems may be a cost-effective and low-tech alternative or additional wastewater treatment solution [44, 21].

Researchers Rousseaua, et al. investigated the efficacy of reusing water in a built wetland (2008) Treated effluent's quality determines whether or not it may be reused for irrigation of crops, flushing of toilets, watering of gardens, golf courses, and public parks. Additional causes of wetland segregation failures include sloppy upkeep and malfunctions in operation. Mosquitoes and the unpleasant scents they produce are another issues in the swamp. Large cities are undesirable for land usage since they demand so much space, and the cost of land is substantially higher in rural regions and low-population cities. Low operation and maintenance expenses mean that more specialized workers are unnecessary. Constructed wetlands, when planned and managed properly, may provide low-cost effluent fit for use and a habitat for animals at a comparatively cheap cost[33].

In their study, Gunes et al. analyzed the efficacy of a three-tank septic system in treating high-strength home wastewater (2012). Macrophytes and algae were utilized as filter media in the FWS CWs, with a retention time of 29.1 days for a daily flow of 462 m3d-1. System efficiency for removing total suspended solids (TSS), biochemical oxygen demand (BOD), total nitrogen (TN), and total phosphorus (TP) was 86%, 92%, 56%, and 43%, respectively. The septic tank was able to remove 60% of the TSS, but it did a poor job of filtering out the other contaminants. Therefore, adsorbing materials should be employed as CW substrates to maximize phosphorus removal. Treatment efficacy was also shown to be affected by the hydraulic retention time (HRT). As a result of the high HRT used, organic materials and nitrogen were efficiently removed[20].

Vymazal et al. (2009) state that suspended solids can be removed using filtration and sedimentation, while Stefanakis (2014) reports that organic materials can be removed through microbial decomposition (2013). There is a lot of nitrogen removal from the environment due to anaerobic nitrification and denitrification of nitrate at the base of the food chain. Phosphorus (P) is eliminated slowly compared to other contaminants and pathogens (such as heavy metals). Because phosphorus is primarily eliminated by adsorption or precipitation, limiting water-to-medium contact is crucial [34, 43].

Researchers Almuktar (2018) and Kadlec (2017) (2008), However, this CW has a large footprint and requires a substantial amount of land, rendering it inappropriate for use as a wastewater treatment system for agricultural reuse. Due to the significant danger of human pathogen exposure, FWS CWs are also seldom employed for secondary wastewater treatment; nonetheless, they are used for advanced effluent treatment[2,23].

Tuttolomondo et alresearch .'s aimed to determine how evapotranspiration affected the efficiency of a pilot-scale HSFCW treating secondary effluent from an activated sludge treatment facility (2016). There were three individual sections, and each was operating at an HLR of 0.12 meters per day with silica quartz river gravel. We used units with no plants, Cyperusalternifolius plants, and Typhalatifolia plants to simulate these variations. A higher percentage of BOD and COD were removed from planted CWs compared to those that weren't planted. However, unplanted areas had lower evapotranspiration rates than planted areas. Cumulative evapotranspiration was found to be greater in Typhalatifolia than in any of the other plants tested (ETc). Since evaporation throws water balances off and leads to water loss, which makes wastewater reuse in agriculture costly, it must be taken into account while planning CW construction in dry and semi-arid regions[37].

Using sand, clay, and iron powder, Witthayaphirom et al. (2021) investigated HSSF CWs that purified landfill leachate. Clearance rates for BOD and COD increased from 69% and 63% in the first year to 92% and 91.9% in the third year, respectively. Increased microbial activity over the summer resulted in the more organic matter being consumed. Beneficial treatment results were achieved by iron adsorption, precipitation, and complexation [45].

The micro-pollutant removal efficiency was also investigated by Witthayaphirom et al (i.e., DEP, DBP, 2,6- DTBP, BHT, and DEHP). The HSSF CW mass removal rates ranged between 64.4-66.1% and 73.3-91.4 percent in the first year of operation. For organic micropollutants, adsorption and biodegradation were the predominant removal methods, while their relative contribution to total removal varied. Increased adsorption and biofilm growth occurred because iron and clay in the substrate increased the specific area of the medium[45].

According to Ezzat and Moustafa(2021), a dynamic roughing filter (DRF) was followed by three horizontal free water surface flow wetland mesocosms. FWS CWs with soil or soil treated with zeolite were used to grow Cyperus papyrus. Organic loads in the influent were decreased by 69% for BOD5, 55% for TSS, 40% for NH3+, and 30.02% for Fe thanks to the pre-treatment unit. The system that utilized soil treated with zeolite was able to remove 84.3% of BOD5, 76.3% of TSS, 98.8% of NH3 +, and 94.6% of Fe over the summer. The wastewater was suitable for re-use in irrigation since it met all FAO standards. The zeolite in the CW bed increased the surface area available for biofilm development and biodegradation, which improved the efficiency of the treatment. To get rid of NH4 +, TP, and metals, the zeolite acted as a cation exchange agent. In warm months, this method was shown to be 99.7% effective against total coliform, 99.4% effective against fecal coliform, and 98.8% effective against E. coli. The outcomes deteriorated in the winter. The bacterial quality was up to World Health Organization standards, thus there were no limitations placed on using the water for irrigation. The results of this investigation show that Cyperus papyrus (L.) root extracts are just as effective as the common antibiotic Amoxycillin/clavulanate at preventing the growth of harmful bacteria. Root extracts from harvested plants were discovered to have six different antibacterial and antioxidant chemicals[16].

Two types of plants were used in the pilot-scale evaluation of VSSF, HSSF, and FWS CWs by Zeng et al.(2020) (i.e., Thalia dealbata and Canna indica). Compared to HSSF and FWS CWs, VSSF CWs were more effective in removing COD, NH4+-N, TN, and TP. The dissolved oxygen levels in VSSF CWs allowed for more efficient COD degradation and TP removal compared to other systems. This form of artificial wetland was not effective at removing NO3—N because of the aerobic conditions present (3.6-5.8 mg/L DO). The CWs at FWS and HSSF benefited from the decreased levels of NO3-N. In comparison to FWS CWs and HSSF CWs, VSSF CWs had more nitrifiers, aerobic denitrifiers, methanotrophs, and phosphorus removal bacteria, which resulted in greater COD, NH3+-N, TN, and TP removal efficiency[46].

To combat the effects of frozen ground, Liang et al.(2020) created a whole new type of wetland. Wastewater was heated using shallow geothermal energy and a VSSF CW and two HSSF CWs. The microbial decomposition of NH4 +-N and TN was enhanced in the engineered wetland. The overall removal rate was above average, at 54.8%. In general, TP was removed at a rate of 77.7%, suggesting that it is unaffected by low temperatures since phosphorus is mostly removed by adsorption on the substrate employed (zeolite, volcanic rock, and steel slag)[24].

Evaluation of a VSSF/CW hybrid CW FWS was conducted by Nguyen et al. (2020). The VSSF CW is composed of layers of expanding clay, sandy soil, sand, and gravel, and is home to a crop of Colocasiaesculenta. Dracaena sanderiana was introduced to the FWS CW. At 0.02 to 0.12 m/d of hydraulic loading, the system functioned for 21 weeks. With a rise in dissolved oxygen from 0.22 to 6.3 mg/L, the water quality was noticeably enhanced. TSS removal was effective in 76% of cases. Intensifying HLR and velocities disrupted performance. (74% reduction in BOD5) Because of the higher HLR, clearance efficiency dropped from 82-80% in stages II and III (0.02 m/d and 0.04 m/d, respectively) to 59% in phase IV (0.12 m/d). In fact, the method reduced coliforms by 84%! Holding Water Back Effluent total coliform clearance may be affected by a variety of factors, including but not limited to time, vegetation, substrate materials, dissolved oxygen, pH, and so on. Moreover The effluent was clean enough to be used for agricultural irrigation in Vietnam and other countries, demonstrating the efficacy of artificial wetlands in this regard[28].

Torrens et al. (2020) conducted a large-scale pilot experiment to evaluate wetland performance. The hybrid CW was developed by combining a CW with horizontal subsurface flow and two phases of French Reed Bed (FRB) flow. Pre-treatment ideas included installing bar racks in settlers' tanks. Filling in the different building phases required a wide variety of materials, including Silex, Granite, River gravel, and River sand. ' Typha was only planted in HSSF CW, while Phragmites were used in all other systems. Treatment effluent was determined to have a very high concentration. The results showed that the total removal rates for COD, BOD5, TSS, TN, and PO4 3- were 90%, 99.5%, 98.3%, 80.9%, and 90%, respectively[36].

**7. Conclusion**

Constructed wetlands have gained popularity across the world as evidence of their effectiveness in treating various types of wastewater has accumulated in recent years. This review, along with other studies on the topic from around the world, demonstrates that the treatment performance of different types of constructed wetlands (FWS, HSSF, VSSF, and hybrid CWs) has been evaluated when operating with different design and operational parameters (such as vegetation types, substrates, temperatures, hydraulic retention times, organic loading rates, etc.). This research suggests that the efficacy of conventional treatments may be on par with or even higher than that of CWs in some situations. Although all artificial wetlands (TSS, COD, BOD, etc.) are extremely successful in removing conventional pollutants, VSSF CWs exceed FWS and HSSF CWs in terms of oxygen transfer rates. They can also filter out emerging contaminants and the metals that are contributing to an already hazardous environment. High hydraulic retention durations, small media sizes, and multistage or hybrid CWs are all effective at reducing microbial contamination, which is notoriously difficult to eradicate. Studies have shown time and time again that CWs produce high-quality effluent that can be reused in farming. As a result, CWs are viewed as a sustainable, low-cost, and energy-efficient option for rural sanitation in far-flung places, with the bonus of producing effluents that may be recycled in agriculture.

**Recommendation**

It is crucial for a sustainable environment to maintain the CWs operating and to expand their coverage area. There is potential for these species to make a positive impact on ecological processes. CWs are a viable, low-cost, and energy-efficient alternative treatment technology for rural sanitation in far-flung areas.

**References**

[1] Al-Baldawi, I.; Abdullah, S.R.S.; Anuar, N.; Suja, F.; Idris, M. Performance assessment of pilot horizontal sub-surface flow constructed wetlands for removal of diesel from wastewater by Scirpusgrossus. Water Sci. Technol. **2013**, 68, 2271–2278.

[2] Almuktar, S.A.A.A.N.; Abed, S.N.; Scholz, M. Wetlands for wastewater treatment and subsequent recycling of treated effluent: A review. Environ. Sci. Pollut. Res. **2018**, 25, 23595–23623.

[3] Ávila, C.; Pedescoll, A.; Matamoros, V.; Bayona, J.M.; García, J. Capacity of a horizontal subsurface flow constructed wetland system for the removal of emerging pollutants: An injection experiment. Chemosphere **2010**, 81, 1137–1142.

[4] Bakhshoodeh, R.; Alavi, N.; Majlesi, M.; Paydary, P. Compost leachate treatment by a pilot-scale subsurface horizontal flow constructed wetland. Ecol. Eng. **2017**, 105, 7–14.

[5] Baptestini, G.C.F.; Matos, A.T.; Martinez, M.A.; Borges, A.C. Hydraulic Conductivity Variability in Horizontal Subsurface Flow Constructed Wetlands. Eng. Agr*í*c. **2017**, 37, 333–342.

[6] Brix, H. Do macrophytes play a role in constructed treatment wetlands? *Water Sci. Technol.* **(1997)**,**35**(5): 11-17.

[7] Canter, L.W., Malina, LF., Reid, G.W., Kung-Chen, G., Lewis, S., “Wastewater disposal and treatment”, In: Reid, W.G. (Ed.), Appropriate Methods of Treating Water and Wastewater. Ann Arbor Science, **(1982)**, pp. 207–270.

[8] Cooper, P. F., Job, G. D., Green, M. B. &Shutes, R. B. E. Reed Beds and Constructed Wetlands for Wastewater Treatment. WRc Publications, Medmenham, Marlow, UK, **(1996)**.

[9] Cooper, P. F. The performance of vertical flow constructed wetland systems with special reference to the significance of oxygen transfer and hydraulic loading rates. Water Sci. Technol. **(2005)**, **51**(9): 81-90.

[10] Crites, R. W., Middlebrooks, E. J. & Reed, S. C. Natural wastewater treatment systems. CRC Press: Boca Raton, FL, **(2005)** , pp. 552.

[11] Critical Design Parameters for ConstructedWetlandsNaturalWastewater Treatment Systems2 October **2021**.

[12] Christofilopoulos, S.; Kaliakatsos, A.; Triantafyllou, K.; Gounaki, I.; Venieri, D.; Kalogerakis, N. Evaluation of a constructed wetland for wastewater treatment: Addressing emerging organic contaminants and antibiotic-resistant bacteria. New Biotechnol. **2019**, 52, 94–103.

[13] David M.G., James, L.A., and Christopherson, S.H. AxlerRuch., A Report of Constructed Wetlands, University of Minnesta EPA, 1993, “Constructed Wetlands for Wastewater Treatment and Wild Life Habitat” : 17 case studies, EPA, **(2002),** 832 – R – 005.

[14] Dan, T.H.; Quang, L.N.; Chiem, N.H.; Brix, H. Treatment of high-strength wastewater in tropical constructed wetlands planted with Sesbaniasesban: Horizontal subsurface flow versus vertical downflow. Ecol. Eng. **2011**, 37, 711–720.

[15] Donde, O.O. Wastewater Management Techniques: A Review of Advancement on the Appropriate Wastewater Treatment Principles for Sustainability. Environ. Manag. Sustain. Dev. **2017**, 6, 40–58.

[16] Ezzat, S.M.; Moustafa, M.T. Treating wastewater under zero waste principle using wetland mesocosms. Front. Environ. Sci. Eng. **2021**, 15, 59.

[17]. Gikas, G.D.; Tsihrintzis, V.A. On-site treatment of domestic wastewater using a small-scale horizontal subsurface flow constructed wetland. Water Sci. Technol. **2010**, 62, 603–614.

[18] Gikas, G.D.; Tsihrintzis, V.A. A small-size vertical flow constructed wetland for on-site treatment of household wastewater. Ecol. Eng. **2012**, 44, 337–343.

[19] Greenway M., “Nutrient Content of Wetland Plants in Constructed Wetland Receiving Municipal Effluent in Tropical Australia”, Water Sci. Technol**(1997),**35, 135-142.

[20] Gunes, K.; Tuncsiper, B.; Ayaz, S.; Drizo, A. The ability of free water surface constructed wetland system to treat high strength domestic wastewater: A case study for the Mediterranean. Ecol. Eng. **2012**, 44, 278–284.

[21] Kadlec, H.R., Knight, R.L., “Treatment Wetlands”, Lewis, Boca Raton, New York, London, Tokyo, **(1996),** p. 893.

[22] Kadlec, R. H. & Wallace, S. D. Treatment Wetlands, 2nd ed. CRC Press, Boca Raton, FL, **(2008)** , pp. 1016.

[23] Kadlec, R.H.;Wallace, S. Treatment Wetlands; CRC Press: Boca Raton, FL, USA, **2008**; ISBN 9781566705264.

[24] Liang, M.Y.; Han, Y.C.; Easa, S.M.; Chu, P.P.;Wang, Y.L.; Zhou, X.Y. New solution to build constructed wetland in cold climatic region. Sci. Total Environ. **2020**, 719, 137124.

[25] Mander, Ü. &Jenssen, P. D. (eds.) Constructed wetlands for wastewater treatment in cold climates. WIT Press, Southampton, UK, **(2003)**, pp. 325.

[26] Mitsch, W. J. &Gosselink, J.G. Wetlands. John Wiley and Sons, Hoboken, NJ, USA,**( 2007)**, pp. 582.

[27] Nguyen, P.M.; Afzal, M.; Ullah, I.; Shahid, N.; Baqar, M.; Arslan, M. Removal of pharmaceuticals and personal care products using constructed wetlands: Effective plant-bacteria synergism may enhance degradation efficiency. Environ. Sci. Pollut. Res. **2019**, 26, 21109–21126.

[28] Nguyen, X.C.; Nguyen, D.D.; Tran, Q.B.; Nguyen, T.T.H.; Tran, T.K.A.; Tran, T.C.P.; Nguyen, T.H.G.; Tran, T.N.T.; La, D.D.; Chang, S.W.; et al. Two-step system consisting of novel vertical flow and free water surface constructed wetland for effective sewage treatment and reuse. Bioresour. Technol. **2020**, 306, 123095.

[29] Nivala, J.; Headley, T.;Wallace, S.; Bernhard, K.; Brix, H.; van Afferden, M.; Müller, R.A. Comparative analysis of constructed wetlands: The design and construction of the ecotechnology research facility in Langenreichenbach, Germany. Ecol. Eng. **2013**, 61,

527–543.

[30] Perdana, M.C.; Sutanto, H.B.; Prihatmo, G. Vertical Subsurface Flow (VSSF) constructed wetland for domestic wastewater treatment. IOP Conf. Ser. Earth Environ. Sci. **2018**, 148, 012025.

[31] Reddy, K.R. and Sultan, D.L., “Water Hyacinths for Water Quality Improvement and Biomass Production”, J. Environ. Qual. **(1984),** 13, 1-8.

[32] Reddy, K.R. and De Busk, W.X., **,** “Nutrient Removal Potential of Selected AquatixMacrophytes”, J. Environ. Qual. **(1985),** 14, 459-462.

[33] Rousseau, D.P.L., Lesage, E., Story, A., Vanrolleghem, P.A., Pauw, N. De,

“Constructed wetlands for water reclamation”, Desalination, **(2008),** 218, pp. 181–189.

[34] Stefanakis, A.; Akratos, C.S.; Tsihrintzis, V.A. Vertical Flow Constructed wetlands: Eco-engineering Systems for Wastewater and Sludge Treatment; Elsevier: Amsterdam, The Netherlands, **2014**.

[35] Thorslund, J.; Jarsjo, J.; Jaramillo, F.; Jawitz, J.W.; Manzoni, S.; Basu, N.B.; Chalov, S.R.; Cohen, M.J.; Creed, I.F.; Goldenberg, R.; et al. Wetlands as large-scale nature-based solutions: Status and challenges for research, engineering, and management. Ecol. Eng. **2017**, 108, 489–497.

[36] Torrens, A.; de la Varga, D.; Ndiaye, A.K.; Folch, M.; Coly, A. Innovative multistage constructed wetland for municipal wastewater treatment and reuse for agriculture in Senegal. Water **2020**, 12, 3139.

[37] Tuttolomondo, T.; Leto, C.; La Bella, S.; Leone, R.; Virga, G.; Licata, M. Water balance and pollutant removal efficiency when considering evapotranspiration in a pilot-scale horizontal subsurface flow constructed wetland in Western Sicily (Italy). Ecol. Eng. **2016**, 87, 295–304.

[38]Vymazal, J., “Horizontal Subsurface Flow and Hybrid Constructed wetland System for Wastewater Treatment”, Ecological Engineering, **(2005),** 24, 478-490.

[39]Vymazal, J. Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. **(2007)**, 380: 48-65.

[40]Vymazal, J. ConstructedWetlands for wastewater Treatment: Five Decades of Experience. Environ. Sci. Technol. **2011**, 45, 61–69.

[41] Vymazal, J. &Kröpfelova, L**.** Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow. Springer, Dordrecht,**(2008)** , pp. 566.

[42] Vymazal, J., Brix, H., Cooper. P. F., Green, M. B. & Haberl, R. (eds) Constructed Wetlands for Wastewater Treatment in Europe. Backhuys Publishers, Leiden, The Netherlands, **(1998)** , pp. 366.

[43] Vymazal, J. The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. Water Res. **2013**, 47, 4795–4811.

[44] Watson, J.T., Sherwood, S. C., Kadlec, R.H., Knight, R.L., Whitehouse, A.E.,

“Performance expectations and loading rates for constructed wetlands”. In: Hammer, D.A. (Ed.), Constructed Wetlands for Wastewater Treatment. Lewis, Chelsea**, (1989)**, pp. 319–351.

[ 45] Witthayaphirom, C.; Chiemchaisri, C.; Chiemchaisri,W.; Ogata, Y.; Ebie, Y.; Ishigaki, T. Long-term removals of organic micropollutants in reactive media of horizontal subsurface flow constructed wetland treating landfill leachate. Bioresour. Technol. **2020**, 312, 123611.

[46] Zeng, L.; Tao, R.; Tam, N.F.; Huang,W.; Zhang, L.; Man, Y.; Xu, X.; Dai, Y.; Yang, Y. Differences in bacterial N, P, and COD removal in pilot-scale constructed wetlands with varying flow types. Bioresour. Technol. **2020**, 318, 124061.