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# Vetiver-Based Vertical Helophyte Filtration Systems for Sustainable Backyard Swine Wastewater Management: A Review

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## ABSTRACT

Swine wastewater, particularly from backyard production systems, represents a significant environmental challenge due to its high concentrations of organic matter, nutrients, and microbial contaminants. In many developing regions, including the Philippines, small-scale swine farmers often lack access to efficient and affordable wastewater treatment systems, leading to the discharge of untreated effluents into the environment. This review synthesizes current knowledge on the application of Vertical Helophyte Filtration Systems (VHFS) as a sustainable, nature-based solution for treating swine wastewater. VHFS integrates physical, chemical, and biological processes through the use of filter media, microbial communities, and helophytic plants to reduce pollutant loads. Particular emphasis is given to the role of vetiver grass (*Chrysopogon zizanioides*), which has demonstrated strong phytoremediation potential due to its extensive root system, high tolerance to environmental stress, and capacity for nutrient uptake and contaminant stabilization. Evidence from existing studies indicates that vetiver-based filtration systems can achieve substantial reductions in biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients, suspended solids, and selected emerging contaminants. Additionally, treated effluent may be reused for agricultural purposes, contributing to improved water use efficiency and reduced freshwater demand. Despite these advantages, system performance is influenced by factors such as substrate composition, hydraulic retention time, plant density, and pollutant loading, highlighting the need for site-specific optimization. This review underscores the potential of vetiver-based VHFS as a cost-effective and environmentally sustainable wastewater management approach for backyard swine production, while also identifying key research gaps and opportunities for system improvement and wider adoption.

**Keywords:** Vetiver grass; Vertical Helophyte Filtration System; swine wastewater; phytoremediation; sustainable agriculture

## INTRODUCTION

The agriculture sector utilizes about 70% of global water for crop production, leading to significant wastewater generation [44]. Untreated agricultural effluents are a major contributor to the global deterioration of water quality, making wastewater pollution a critical environmental concern. According to Vaishnav et. al., one major source of environmental pollution is wastewater from poultry and livestock accounted in China for about 76.8% discharged from the source [47].

Pork remains the second most consumed meat worldwide, with global production reaching over 118 million metric tons in 2018. In the conducted Backyard Livestock and Poultry Survey (BLPS) of the Philippines Statistics Authority, 22,000 households in the country are backyard farmers. Backyard production accounted for more than 64.3% of total swine production in 2020, and for the commercial production only made up 37.7% [19]. Larger assessments also indicate that wastewater production per head in commercial swine facilities may range from approximately 17 to 30 liters per day, and in systems with poor management practices the volume can increase to as much as 50 liters per pig per day, highlighting the variability across production scales and management intensities (Global Methane Initiative, Resource Assessment for Agriculture in the Philippines, 2025). While backyard farming provides livelihoods and bolsters food security, it often lacks the infrastructure for managing the environmental impacts of livestock waste. Unlike commercial farms, which typically have wastewater treatment systems to handle effluent, backyard farms frequently discharge untreated wastewater directly into nearby water bodies or soil, which can lead to water pollution, eutrophication, and public health risks [8,46].

Swine production generates substantial volumes of wastewater—about 4–8 liters per pig each day—that carry a heavy load of pollutants. Typical concentrations include total nitrogen (600–2100 mg/L), total phosphorus (100–250 mg/L), chemical oxygen demand or COD (3,000–15,000 mg/L), and biological oxygen demand or BOD (2,000–8,000 mg/L), along with large amounts of organic matter. The wastewater also tends to have a pH ranging from 7.0 to 8.5, which favors the persistence of ammoniacal nitrogen and can intensify odor emissions [11, 24, 51, 52]. If left untreated, this nutrient-rich effluent can lead to severe water pollution, driving eutrophication, oxygen depletion, and ecosystem damage. Recent studies further emphasize that swine wastewater contains not only nutrients but also suspended solids, volatile fatty acids, heavy metals, and even residues of veterinary pharmaceuticals, all of which heighten its environmental risks [23].

Backyard and small-scale swine farmers are increasingly adopting low-cost and nature-based wastewater management practices to address the high organic and nutrient loads of pig manure and wash water that threaten soil and water quality. The widely used approach is the implementation of constructed wetland systems, which use vegetation, soil substrates, and microbial processes to filter and reduce pollutants such as suspended solids, organic matter, and nitrogen from swine wastewater, making the effluent safer for land application or discharge [25, 45]. Alongside wetlands, biodigesters are promoted in rural contexts for treating pig waste while generating biogas energy, as demonstrated by agricultural research initiatives in Mexico where biodigesters combined with lagoon systems reduce organic load and produce usable methane [32].

One promising solution for managing wastewater in backyard swine farming is the use of Vertical Helophyte Filtration Systems (VHFS), a type of constructed wetland that employs helophytic plants to naturally treat effluents. By combining microbial activity, plant nutrient uptake, and sedimentation, VHFS can significantly reduce organic and nutrient loads, offering a sustainable and cost-effective option for small-scale farmers [53]. Despite these benefits, the system requires considerable land area for optimal performance, which may pose challenges for farms with limited space. Seasonal variations, particularly changes in temperature and plant dormancy, can also influence treatment efficiency. Regular maintenance is essential to prevent sediment accumulation and clogging, while the relatively high upfront construction cost may discourage adoption among low-income farmers, even though long-term benefits are substantial.

Reviews on vetiver-based remediation highlight its effectiveness in the removal and stabilization of nutrients, heavy metals, and selected organic pollutants from contaminated water and soil. The species is characterized by a deep and dense root system that forms an extensive rhizosphere, enhancing pollutant adsorption, stimulating microbial activity, and facilitating nutrient uptake. Moreover, vetiver demonstrates high tolerance to adverse environmental conditions, including acidity, alkalinity, salinity, and heavy metal stress, making it a suitable candidate for use in challenging treatment environments [20]. The integration of vetiver-based Vertical Helophyte Filtration Systems (VHFS) can further contribute to improving water use efficiency by enabling the safe reuse of treated wastewater for agricultural or farm-related activities. Treated effluent can be repurposed for irrigation or for cleaning animal pens, thereby reducing reliance on freshwater withdrawals and lowering the overall water footprint of swine production [12]. This dual role—mitigating wastewater pollution while promoting resource recovery—aligns VHFS with principles of circular economy and sustainable agriculture.

**Swine Production in the Philippines**

Swine production is a vital component of the agricultural sector in the Philippines, contributing significantly to the country's food security and rural livelihoods. According to the Philippine Statistics Authority [38], the swine industry is the second-largest contributor to the livestock subsector, accounting for a substantial share of total agricultural output. Swine farming in the Philippines is broadly categorized into two systems: small-scale backyard operations and large-scale commercial enterprises. Backyard pig farming, which involves raising fewer than 20 pigs, remains dominant and is practiced by many rural households as a primary or supplementary source of income [9]. In contrast, commercial pig farms focus on large-scale production, utilizing modern technologies and intensive management practices to meet the growing demand for pork.

The demand for pork, a staple protein source in the Filipino diet, has driven the growth of the swine industry over the years. Pork consumption remains high, with the average Filipino consuming approximately 15 kilograms of pork annually [31]. However, the industry faces numerous challenges, including fluctuating feed costs, disease outbreaks, and environmental concerns. The African Swine Fever (ASF) outbreak in recent years has had devastating effects on the local swine industry, leading to a significant reduction in hog inventory and increased pork prices [37]. Efforts to combat ASF have included government-initiated vaccination campaigns, biosecurity measures, and repopulation programs aimed at reviving the industry.

Environmental issues also pose a significant challenge for swine production in the Philippines, particularly in terms of managing waste from piggery operations. Small-scale pig farms, which often lack proper waste management systems, contribute to water pollution and greenhouse gas emissions. According to Espaldon et al., untreated piggery wastewater, rich in organic matter, nitrogen, and phosphorus, can lead to eutrophication in water bodies [22]. Recognizing this issue, the Philippine government has encouraged the adoption of environmentally sustainable practices, including the use of biogas systems and constructed wetlands for wastewater treatment [15]. Despite these challenges, the swine industry remains a critical driver of rural development and economic growth in the Philippines. The government, in collaboration with private stakeholders, continues to promote programs aimed at enhancing the productivity and sustainability of swine production. These include training initiatives for smallholder farmers, access to credit and feed subsidies, and the adoption of modern breeding and health management practices. Moving forward, the focus on balancing productivity with sustainability will be crucial in ensuring the long-term growth of the Philippine swine industry.

**Wastewater Production**

Wastewater production is a global environmental challenge stemming from domestic, industrial, and agricultural activities. Globally, it is estimated that 80% of wastewater generated by human activities is discharged untreated into the environment, posing significant risks to public health and ecosystems (UNESCO, 2017). In developing countries like the Philippines, wastewater production is a growing concern due to rapid urbanization, population growth, and intensifying agricultural and industrial activities (ADB, 2019). Wastewater is broadly classified into two categories: domestic wastewater from households and municipal sources, and industrial wastewater from manufacturing, agriculture, and other sectors [7].

The management of wastewater in the Philippines is strongly guided by environmental policies under the Philippine Clean Water Act of 2004 (RA 9275) and its implementing rules, such as DENR Administrative Order (DAO) 2004-36. This law highlights the government's commitment to protect water bodies from pollution caused by domestic, agricultural, and industrial activities. DAO 2004-36, in particular, lays down the procedures and standards for wastewater discharge, emphasizing that all establishments generating wastewater must comply with set effluent quality guidelines before releasing it into water bodies. By requiring monitoring, treatment, and reporting, the regulation ensures that wastewater management aligns with national water quality objectives, safeguarding both ecosystems and communities [16].

Complementing this, the issuance of Wastewater Discharge Permits (WWDP) serves as a regulatory tool for the Department of Environment and Natural Resources (DENR) through its Environmental Management Bureau (EMB). Entities such as industries, commercial establishments, piggeries, and poultry farms are mandated to secure permits prior to discharging wastewater. The permitting process involves technical evaluations, submission of engineering reports, wastewater line layouts, laboratory analyses of effluent, and compliance with water quality standards. Renewal also requires proof of compliance, including laboratory test results and self-monitoring reports, ensuring accountability and consistency in pollution control efforts [16].

Taken together, these regulations highlight the Philippine government's dual approach: setting clear effluent standards (through DAO 2004-36) and enforcing permit-based regulation (through WWDP issuance). These mechanisms not only regulate pollution but also encourage industries and even agricultural producers to invest in proper wastewater treatment facilities. For small-scale operations such as backyard pig farming, these frameworks pose challenges in compliance due to financial and technical limitations, but they also create opportunities to explore low-cost, sustainable treatment systems like the Vertical Helophyte Filtration System (VHFS), which can bridge the gap between regulation and practice.

**Effluent Standard under DAO 2016-08**

Wastewater management is a critical environmental concern in the Philippines, particularly in the agricultural sector, where livestock farming is widespread. The Philippine Clean Water Act of 2004 (Republic Act No. 9275) and its implementing guidelines under DENR Administrative Order (DAO) No. 2016-08 establish effluent standards (see Table 1) to regulate the discharge of wastewater into natural water bodies. These standards are intended to maintain ecological balance and protect public health by requiring wastewater to meet acceptable levels of parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients, and microbial counts before discharge [16].

Table 1. Effluent Standard (Amendment to DAO 2021-19, section 7)

| Parameter | Unit | Water Body Classification | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | AA | A | B | C | D | SA | SB | SC | SD |
| **Physio-Chemical** | | | | | | | | | | |
| Ammonia as $NH_3$-N | mg/L | NDA | 2 | 3 | 4 | 9 | NDA | 3 | 4 | 9 |
| BOD | mg/L | NDA | 20 | 30 | 50 | 120 | NDA | 30 | 100 | 150 |
| Boron | mg/L | NDA | 4 | 4 | 4 | 12 | NDA | 4 | 25 | 100 |
| Chloride | mg/L | NDA | 350 | 350 | 450 | 500 | NDA | n/a | n/a | n/a |
| COD | mg/L | NDA | 60 | 60 | 100 | 200 | NDA | 60 | 200 | 300 |
| Color | TCU | NDA | 100 | 100 | 150 | 300 | NDA | 100 | 150 | 300 |
| Cyanide as free Cyanide | mg/L | NDA | 0.14 | 0.14 | 0.2 | 0.4 | NDA | 0.04 | 0.2 | 0.4 |
| Flouride | mg/L | NDA | 2 | 2 | 2 | 4 | NDA | 3 | 3 | 6 |
| Nitrate as $NO_3$-N | mg/L | NDA | 14 | 14 | 14 | 30 | NDA | 20 | 20 | 30 |
| pH (Range) | mg/L | NDA | 6.0-9.0 | 6.0-9.0 | 6.0-9.5 | 5.5-9.5 | NDA | 6.5-9.0 | 6.0-9.0 | 5.5-9.5 |
| Phosphate | mg/L | NDA | 1 | 1.5 | 4 | 10 | NDA | 2 | 4 | 10 |
| Selenium | mg/L | NDA | 0.02 | 0.02 | 0.04 | 0.08 | NDA | 0.02 | 0.2 | 0.4 |
| Sulfate | mg/L | NDA | 500 | 500 | 550 | 1,000 | NDA | - | - | - |
| Surfactants (MBAS) | mg/L | NDA | 2 | 3 | 15 | 30 | NDA | 3 | 15 | 30 |
| Temperature | °C | NDA | 3 | 3 | 3 | 3 | NDA | 3 | 3 | 3 |
| Total Suspended Solids (TSS) | mg/L | NDA | 70 | 85 | 100 | 150 | NDA | 70 | 100 | 150 |

The DENR Administrative Order No. 2016-08 also identifies standard parameters for effluent discharges based on industry classification. Under this order, Category A includes Agriculture, Forestry, and Fishing, as shown in Table 2 [16].

Table 2. Significant Effluent Quality Parameters per Sector (DAO 2016-08, Section 7)

| PSIC CODE | Industry Code | Significant Parameters |
|---|---|---|
| **A. Agriculture, Forestry, and Fishing** | | |
| 014 | Animal Production | BOD, Total Suspended Solids (TSS), Total Coliform, Ammonia, Phosphate |

However, raw swine wastewater often far exceeds these limits, creating a significant compliance challenge for both commercial and backyard farms. For example, the standard for BOD under DAO 2004-36 is 50 mg/L, whereas untreated swine wastewater typically contains 2,000-8,000 mg/L [24, 52]. Similarly, the permissible COD limit is 100 mg/L, yet pig farm effluents commonly range from 3,000-15,000 mg/L [51]. Nutrient concentrations are also alarmingly high. Total nitrogen (TN) in swine effluents can reach 600-2,100 mg/L, while the allowable limit for ammonia (NH3-N) is only 5 mg/L. Total phosphorus (TP), which is regulated at 1 mg/L to help prevent algal blooms, is often present at concentrations of 100-250 mg/L in swine wastewater.

These discrepancies highlight the urgent need for cost-effective treatment systems that can help livestock farms comply with national standards. Conventional wastewater treatment facilities are often too expensive and space-intensive for small-scale farmers, making untreated discharge a common practice. In this context, nature-based solutions such as the Vertical Helophyte Filtration System (VHFS) have gained increasing attention. VHFS uses helophytic plants, microbial activity, and sedimentation processes to naturally reduce pollutants in wastewater. Previous studies have shown that constructed wetlands and VHFS can significantly lower organic loads and nutrient concentrations, making them promising alternatives for smallholder and backyard farms that struggle with regulatory compliance.

By aligning wastewater treatment innovations such as VHFS with regulatory benchmarks, research can help bridge the gap between the actual characteristics of livestock waste and national effluent standards. This not only supports environmental protection but also empowers small-scale farmers by providing affordable solutions for complying with Philippine regulations.

**Significant Parameters for Animal Production Wastewater**

Wastewater from animal production contains a complex mixture of organic matter, suspended particles, nutrients, pathogens, and other contaminants. Its composition depends on the type of livestock, manure handling practices, feed composition, water use, and farm cleaning systems. Recent reviews have described livestock and swine wastewater as typically rich in biochemical oxygen demand (BOD), total suspended solids (TSS), nitrogenous compounds such as ammonia, phosphorus compounds such as phosphate, and microbial contaminants, all of which can degrade water quality when released without adequate treatment [47,55]. These characteristics explain why the DENR identifies BOD, TSS, total coliform, ammonia, and phosphate as significant parameters for Animal Production under PSIC Code 014.

**Biochemical Oxygen Demand**

One of the most important indicators of organic pollution in wastewater because it reflects the amount of dissolved oxygen required by microorganisms to break down biodegradable organic matter. In livestock wastewater, high BOD levels are commonly associated with manure, urine, spilled feed, and wash water. Vaishnav et al., noted that livestock and poultry wastewater is characterized by high organic loading, including elevated BOD, which can adversely affect soil, groundwater, and surface water if not adequately treated [47]. Likewise, Deng et al., emphasized that swine wastewater contains substantial organic matter, with pollution loads high enough to require treatment before discharge or reuse. Elevated BOD in receiving waters can reduce dissolved oxygen levels, stress aquatic organisms, and contribute to ecological imbalance [14].

### Total Suspended Solids (TSS)

It represents the solid particles suspended in wastewater, including fecal matter, undigested feed, bedding materials, and soil particles. TSS is a key parameter in animal production wastewater because excessive solids increase turbidity, reduce light penetration in water bodies, and may carry attached organic matter, nutrients, and pathogens. Reviews on swine wastewater consistently identify TSS as one of the major pollutants in farm effluents [47, 55]. Zhou et al. specifically described swine wastewater as containing high levels of suspended solids together with organic matter and nutrients [55], while Deng et al., highlighted total solids as an important component of pollution load in intensive pig farming systems. Because suspended solids can interfere with downstream treatment and contribute to sludge accumulation and oxygen depletion, TSS remains a fundamental parameter in wastewater monitoring and regulation [14].

### Total Coliform

Total coliform is widely used as an indicator of microbial contamination in wastewater. In animal production systems, manure-derived wastewater may contain fecal bacteria and other microorganisms that pose risks to public health, especially when effluent is discharged into natural waters or reused in agriculture. Vaishnav et al., identified pathogens as one of the defining contaminants of livestock wastewater [47], while Bôto et al., demonstrated that swine wastewater contains hazardous biological contaminants that can be substantially reduced through treatment. Their study reported very high removal of fecal indicator bacteria in constructed wetlands, showing the importance of microbial monitoring in evaluating treatment performance. Although research articles may refer to fecal indicator bacteria using terms such as enterobacteria, enterococci, or coliform-related indicators, the literature consistently supports the inclusion of total coliform as a critical parameter for assessing sanitary quality in animal production wastewater [6].

### Ammonia

It is the major nitrogenous pollutant in animal wastewater and is particularly important in swine production because of the high nitrogen content of urine and manure. Elevated ammonia concentrations are associated with toxicity to aquatic organisms, oxygen demand through nitrification, odor generation, and nutrient enrichment of receiving waters. Zhou et al., reported that raw swine wastewater commonly contains very high concentrations of ammonium nitrogen [55], while Sajjad et al., emphasized that ammonia-rich animal waste contributes to serious ecological problems, including eutrophication and ammonia volatilization [41]. Nagarajan et al. further explained that improper swine wastewater treatment increases ammonium volatilization and related environmental impacts. Because of these risks, ammonia is both a regulatory concern and a treatment priority in animal production wastewater management [34].

### Phosphate

Phosphate is another major pollutant in animal production wastewater because livestock manure contains substantial amounts of phosphorus originating from feed residues and excreta. When discharged into rivers, lakes, or ponds, phosphate can stimulate algal blooms and accelerate eutrophication. Sajjad et al., described nitrogen and phosphorus in animal waste as major causes of eutrophication and algal bloom formation in water bodies [41]. Similarly, Zhou et al., noted that swine wastewater is rich in phosphorus and other nutrients [55], while Nagarajan et al., emphasized that swine wastewater contains abundant nitrogen and phosphorus that must be removed before environmental release. Since phosphorus is less easily removed by some conventional treatment systems, phosphate remains a critical effluent parameter and a frequent target of nutrient recovery technologies in animal wastewater treatment [34].

### Impacts of Wastewater Production

Untreated or poorly managed wastewater has severe environmental and health consequences. Excessive nutrients in agricultural wastewater can lead to eutrophication, resulting in algal blooms and oxygen depletion in water bodies. Industrial wastewater with heavy metals and toxic chemicals can contaminate water supplies, harm aquatic ecosystems, and pose long-term health risks to humans (WHO, 2019). Additionally, pathogens in untreated domestic wastewater are a major cause of waterborne diseases such as cholera, typhoid, and diarrhea, particularly in low-income communities (UNICEF & WHO, 2021).

**Sustainable Wastewater Management Practices**

Recognizing the adverse impacts of wastewater production, many countries, including the Philippines, are adopting sustainable wastewater management practices. Technologies such as constructed wetlands, anaerobic digestion, and bioreactors are being implemented to treat domestic and industrial wastewater [50]. In the agricultural sector, practices like nutrient recycling, integrated farming systems, and biogas production from livestock waste are gaining traction. Government policies and international frameworks, such as the Sustainable Development Goals (SDG 6.3), emphasize the need to reduce wastewater production and improve treatment processes to protect water resources and ecosystems (UN, 2015).

**Vertical Helophytes Filtration System (VHFS)**

The VHFS is an innovative, sustainable approach to water purification that integrates both natural filtration processes and plant-based technologies. It utilizes helophytes, or marsh plants, which thrive in waterlogged environments, as part of the filtration process. These plants, through their root systems, effectively filter pollutants from water, making VHFS an eco-friendly solution for treating wastewater in both urban and rural settings [28]. The VHFS typically operates in a vertical configuration, with water flowing through various layers of substrates planted with helophytes, allowing the system to filter contaminants in a compact and efficient manner [18].

The performance of VHFS is primarily attributed to the physical, chemical, and biological processes facilitated by the plants and the microbial communities in the root zones. Helophytes such as *Typha* (cattails), *Schoenoplectus* (bulrushes), and *Phragmites* (reeds) are commonly used due to their robust growth and ability to uptake nutrients, heavy metals, and organic pollutants from the water [26]. These plants also contribute to oxygenating the water, which supports the microbial breakdown of organic matter and improves overall filtration efficiency [54]. The roots of the plants act as a substrate for beneficial microorganisms, creating a biofilm that accelerates the removal of nitrogen, phosphorus, and other pollutants [39].

Several studies have demonstrated the efficacy of VHFS in removing a wide range of contaminants, including suspended solids, nutrients (especially nitrogen and phosphorus), and pathogenic microorganisms. Research by Di Cristo et al., has highlighted the system's ability to significantly reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in treated water, making it suitable for both domestic wastewater treatment and industrial effluent management [17]. The vertical configuration of the VHFS, which allows for optimal space utilization, also enhances the contact time between water and the filtration medium, further improving treatment performance [30].

In terms of design, the VHFS generally includes multiple layers of gravel, sand, and organic substrates that serve as both a filter and a support structure for the plants and enhance pollutant removal while maintaining permeability and reducing the risk of clogging. The vertical design allows for more efficient use of land and water, especially in areas with limited space. A typical VHFS consists of an inlet chamber receiving pre-settled swine wastewater, followed by a vertical filtration bed composed of layered substrates (gravel, sand, and fine aggregates). Vetiver grass is planted on the surface, allowing wastewater to percolate vertically through the root zone where filtration, adsorption, and microbial degradation occur. The treated effluent is collected through an outlet drainage system and can be reused for irrigation or cleaning purposes (see Figure 1). Studies have shown that the depth and arrangement of these layers, as well as the plant species selected, significantly influence the system's filtration capacity [21]. The addition of a secondary treatment layer, such as activated charcoal, has been shown to further improve the removal of contaminants, particularly organic compounds and micropollutants, which are harder to degrade by plant roots alone [43].

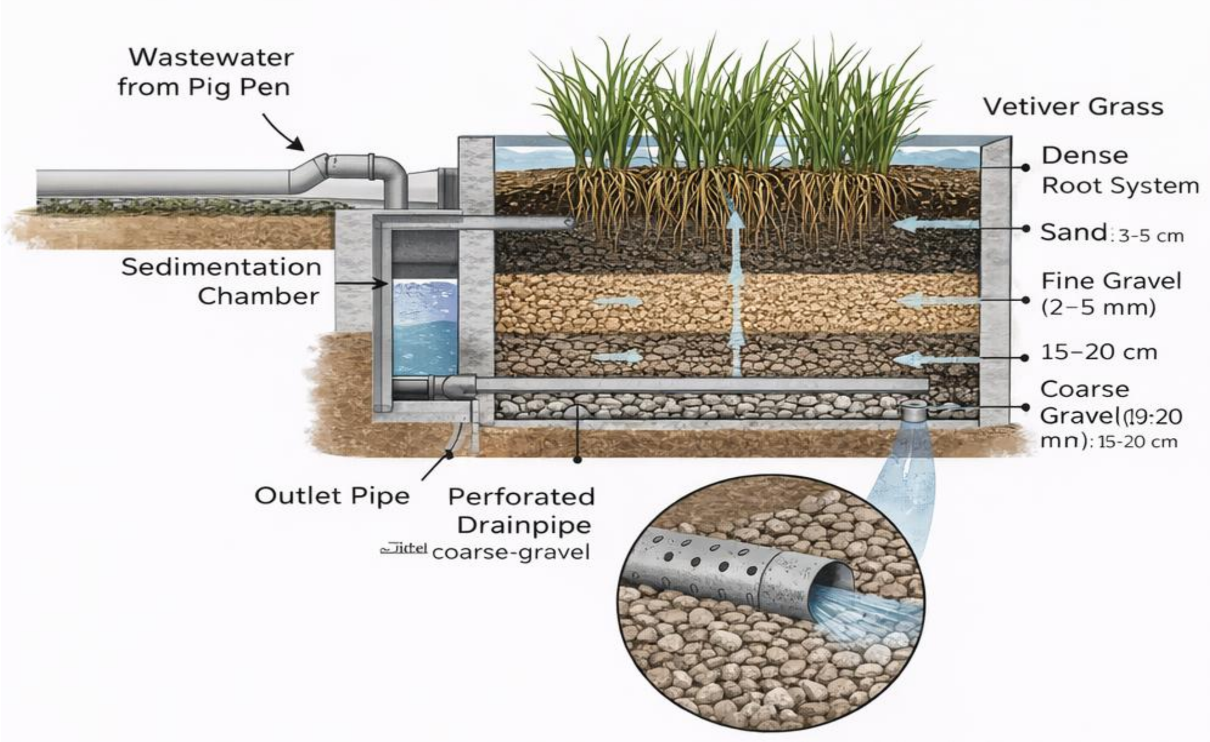


Figure 1. Typical Diagram of a Vertical Helophytes Filtration System (VHFS).

**Cost-Effectiveness of VHFS**

Constructed wetlands, including Vertical Helophyte Filtration Systems (VHFS), are widely recognized as cost-effective wastewater treatment technologies due to their low energy requirements, minimal operation and maintenance costs, and reliance on natural processes. Compared to conventional systems such as anaerobic lagoons or activated sludge processes, these systems require less infrastructure and technical expertise, making them particularly suitable for smallholder and backyard farming operations. In addition, the reuse of treated effluent for irrigation contributes to water conservation and reduces operational costs, thereby enhancing the overall economic feasibility of the system.

As a specific type of constructed wetland, VHFS offers a promising and sustainable solution for decentralized wastewater treatment, particularly in areas where conventional systems are not feasible. Recent studies have focused on improving VHFS performance through integration with complementary technologies, such as membrane filtration and hybrid wetland configurations, to achieve higher treatment efficiencies [5]. Moreover, VHFS contributes to environmental sustainability by requiring minimal energy input while enhancing water quality and supporting ecological functions. This aligns with global efforts toward sustainable water management and green infrastructure development [42]. Future research should therefore focus on optimizing plant selection, substrate composition, and operational parameters to further enhance VHFS performance and adaptability across different environmental conditions.

**Vetiver grass (*Chrysopogon zizanioides*)**

The *Chrysopogon zizanioides* commonly known as the vetiver grass having its diverse applications, such as the extraction of essential oils, making of handicrafts, the prevention of soil erosion and landslides, and also a remediation for environmental contamination and/or soil pollution [49]. Reviews of vetiver-based remediation describe the species as suitable for removing or stabilizing nutrients, heavy metals, and some organic pollutants from contaminated water and soil. Its roots are reported to grow deeply and densely, creating a large rhizosphere that supports pollutant adsorption, microbial activity, and nutrient uptake. Vetiver also tolerates adverse conditions such as acidity, alkalinity, salinity, and heavy-metal exposure, which makes it useful in difficult treatment environments [20].

One of the most important reasons for selecting vetiver in phytoremediation is its tolerance to contamination and its tendency to retain many pollutants within the root zone. A major review reported that vetiver can absorb soluble nutrients such as nitrogen and phosphorus and can also accumulate metals including zinc, copper, nickel, chromium, and lead [13]. The same review noted that vetiver is effective under a broad pH range and under saline or metal-stressed conditions. This makes the species useful not only for pollutant uptake but also for phytostabilization, where contaminants are immobilized or retained mainly in the root system rather than extensively translocated to the shoots [20].

Early work on contaminated soils helped establish vetiver's phytoremediation potential. Chen et al., found that vetiver tolerated high lead concentrations in soil and that lead concentrations were generally much higher in roots than in shoots, indicating strong root retention. Their study also showed that the application of EDTA increased lead translocation to shoots, suggesting that vetiver can function either mainly as a phytostabilizer under normal conditions or as a phytoextractor when assisted by chelating agents. More recent evidence from metal-polluted soils likewise indicates that vetiver accumulates substantial amounts of metals in the root system while showing limited transfer to the aerial parts, supporting its value for in situ stabilization of contaminated land [10]. Beyond soil remediation, many studies have tested vetiver in wastewater treatment. In the study of Badejo et al., a vertical-flow constructed wetland treating municipal wastewater, reported high removal efficiencies, including 98.34% for total suspended solids, 98.95% for free and saline ammonia, 91.44% for total Kjeldahl nitrogen, and 80.65% for COD in some treatment streams. The study concluded that vertical-flow constructed wetlands planted with locally available vetiver are a viable alternative for municipal wastewater treatment [4]. These findings support the practical application of vetiver as a wetland treatment plant where low-cost and locally adaptable technologies are needed.

Table 3. Pollutant Removal Efficiency

| **Study** | **System Type** | **Biochemical Oxygen Demand (BOD)** | **Chemical Oxygen Demand (COD)** | **Total Suspended Solids (TSS)** | **Total Nitrogen (TN)** | **Total Phosphorus (TP)** |
|---|---|---|---|---|---|---|
| Aregu et al. [3] | Horizontal Subsurface-flow Constructed Wetland System | 91.90% | 96.60% | - | 88.70% | 92.20% |
| Badejo et al. [4] | Vertical-flow Constructed Wetland System | - | 80.65% | 98.34% | 91.44% | - |
| Panja et al. [36] | Plug Flow Reactor Based Constructed Wetland System | - | 84.00% | - | 93.00% | 84.00% |
| Velasco [48] | Vertical Subsurface-flow Constructed Wetland System | 93.53% | - | 35.41% | 81.88% | 64.93% |

Similar results have been reported for high-strength industrial wastewater. In Ethiopia, a horizontal subsurface-flow constructed wetland planted with vetiver was used to treat tannery wastewater. At a nine-day retention time, the planted bed reduced BOD, COD, ammonium, nitrate, total nitrogen, phosphate, and total phosphorus by 91.9%, 96.3%, 62%, 86%, 88.7%, 96.3%, and 92.2%, respectively; chromium removal reached 97% at both seven and nine days. The planted wetland performed significantly better than the unplanted control, showing that vetiver can remain effective even under high pollutant loading [3].

Vetiver has also been studied in agricultural wastewater, which is especially relevant to livestock-based systems. A study on swine farm wastewater treated in surface-flow constructed wetlands planted with vetiver found that water depth influenced treatment performance, with 30 cm depth providing better removal of organic substances such as BOD and COD. Total phosphorus showed particularly high removal, averaging about 95.18% to 96.53%.

Although heavy-metal removal was more limited in that study, the results still indicate that vetiver-based wetlands can substantially improve the quality of nutrient-rich farm effluents and may offer a practical option for smaller agricultural operations [40]. Philippine work also supports vetiver's use in wetland treatment. A report on vertical subsurface-flow constructed wetlands for dairy wastewater described vetiver reed bed systems as an economical and environmentally adapted alternative for small farms. The vertical subsurface constructed wetland system planted with vetiver grass was found to be highly effective in treating dairy farm wastewater. The system achieved average removal efficiencies of 35.41% for Total Suspended Solids (TSS), 93.53% for Biochemical Oxygen Demand over five days ($BOD_5$), 64.93% for Total Phosphorus (TP), and 81.88% for Total Kjeldahl Nitrogen (TKN). Additionally, a relationship was observed between the age of the vetiver plants and the corresponding removal efficiencies. The proposed reed bed design operates with a hydraulic retention time of four hours [48].

Aside from nutrients and conventional wastewater parameters, vetiver has shown promise for the treatment of emerging and complex pollutants. In constructed wetland and hydroponic studies, vetiver removed antibiotics such as oxytetracycline and ciprofloxacin and was proposed as a viable green technology for wastewater containing pharmaceutical residues. One study also noted vetiver's tolerance to extreme conditions, including very high nitrate concentrations. In another constructed wetland experiment with PAH-contaminated synthetic wastewater, vetiver was able to take up phenanthrene, pyrene, and benzo[a]pyrene, supporting its applicability to organic contaminant remediation, although pollutant-specific responses and plant growth effects can vary [36]. Study shows that vetiver grass can function both as a phytoremediator and as a useful wetland treatment plant or helophyte in constructed systems. Its effectiveness appears to arise from several interacting mechanisms: direct nutrient uptake, adsorption and retention of contaminants in the root zone, support of rhizosphere microorganisms, filtration and sediment trapping, and tolerance to stressful wastewater conditions. However, published studies also show that treatment efficiency depends on system design, hydraulic retention time, pollutant type, loading rate, substrate, and planting density. Therefore, while vetiver is a strong candidate species, site-specific evaluation remains necessary before recommending it for a given wastewater stream or wetland configuration [20].

**Aggregate Ratio for Wastewater Filtration**

Aggregates are critical components of wastewater filtration systems because they influence hydraulic behavior, solids retention, pollutant filtration, microbial attachment, and the physical support of the filter bed [1, 29]. In constructed wetlands and sand-based filtration systems, media such as sand, gravel, stones, and other aggregates are commonly arranged in layers to improve treatment efficiency and maintain hydraulic performance [1]. This layered arrangement improves filtration because the upper media retain suspended solids and microorganisms through physical filtration and interception, while the underlying substrate provides structural support, drainage, and additional surfaces for microbial growth and biofilm formation [29]. Reviews on constructed wetlands also emphasize that media selection strongly affects the removal of biochemical oxygen demand (BOD), total suspended solids (TSS), nutrients, and microbial contaminants, although there are still no universally accepted design rules for one exact media ratio [1].

Optimal media thickness and composition depend on wastewater characteristics, pollutant targets, and filtration goals. The study on multilayer sand filters for greywater reported an optimized configuration of 33 cm fine sand, 20 cm activated carbon, and 7 cm medium sand, showing that the best arrangement varies according to the treatment objective rather than following a single standard ratio [35].

For wastewater systems where pathogen removal is important, the literature suggests that the depth of the sand layer is especially important. Mulugeta et al., reported geometric mean reductions in total coliforms of 99%, 87%, and 30% for bio-sand filters with top fine sand depths of 220 mm, 120 mm, and 20 mm, respectively. These findings indicate that deeper fine-media layers can substantially improve coliform removal performance in wastewater filtration systems [33]. Based on these findings, it is more accurate to state that sand should occupy the largest share of the media bed when microbial removal is a priority, while gravel or coarser aggregates mainly function as support and drainage layers beneath the finer media [33, 29].

Evidence from constructed wetland reviews likewise shows that substrates play a major role in pollutant removal through filtration, interception, adsorption, and microbial processes, and that different media combinations may be selected depending on whether the treatment priority is organic matter removal, nutrient removal, or pathogen reduction [1, 29]. Therefore, for a thesis or research proposal, the most defensible wording is that the literature supports an optimal practical range or configuration, rather than a universally perfect aggregate ratio [35].

**Water Footprint**

The concept of the water footprint has emerged as an important tool in understanding how water is consumed and polluted across the life cycle of goods and services. It accounts for three key components: blue water (surface and groundwater use), green water (rainfall stored in the soil and used by plants), and grey water (the volume of freshwater required to dilute pollutants to safe levels). In agriculture, which is the largest user of global freshwater, the water footprint provides insights into both direct water use and the hidden water embedded in crop and livestock production [53].

Recent research highlights the need to move from a purely volumetric perspective to an impact-oriented water footprint, which evaluates not only how much water is used but also the ecological consequences of such use. This includes effects on water scarcity, eutrophication, and ecosystem health, making the water footprint a more practical tool for guiding sustainable resource management [2, 7]. Furthermore, studies show that about 20% of global water use is transferred through international trade as "virtual water," underscoring the interconnectedness of water security and food systems worldwide [31].

While methodological differences remain a challenge, the water footprint framework continues to evolve as a valuable basis for designing sustainable strategies, particularly in agriculture and livestock systems. By integrating impact-based approaches and local water availability data, the tool can better guide policies and innovations aimed at reducing water stress and promoting efficient resource use [27].

## CONCLUSION AND RESEARCH PROSPECTS

Swine wastewater, particularly from backyard production systems, poses a significant environmental challenge due to its high organic load, nutrient concentration, and microbial contamination. Conventional treatment systems are often inaccessible to smallholder farmers due to economic and technical constraints, emphasizing the need for low-cost, sustainable, and decentralized treatment technologies. In this context, Vertical Helophyte Filtration Systems (VHFS) emerge as a promising nature-based solution that integrates physical filtration, microbial degradation, and plant-mediated processes to effectively reduce pollutants in wastewater.

The incorporation of vetiver grass (*Chrysopogon zizanioides*) further enhances the functionality of VHFS due to its well-documented phytoremediation capacity, extensive root system, and tolerance to adverse environmental conditions. Evidence from multiple studies confirms that vetiver-based systems can achieve substantial reductions in biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients, suspended solids, and selected contaminants, making them particularly suitable for treating high-strength agricultural effluents such as swine wastewater. Moreover, the potential reuse of treated effluent for irrigation and farm operations contributes to improved water use efficiency and supports circular economy principles in agricultural systems.

Despite these advantages, several gaps remain that warrant further investigation. Future research should focus on optimizing VHFS design parameters, including substrate composition, aggregate ratios, hydraulic retention time, and planting density, to maximize treatment efficiency under varying wastewater characteristics. Comparative studies evaluating vetiver against other helophytes under controlled and field conditions are also needed to establish species-specific performance benchmarks. Additionally, long-term field evaluations in backyard swine production settings are essential to assess system durability, maintenance requirements, and economic feasibility.

Further research should also explore the removal of emerging contaminants, such as antibiotics and pharmaceutical residues, which are increasingly present in livestock wastewater. Integrating VHFS with complementary technologies, such as anaerobic digestion or biochar-based filtration, may enhance treatment performance and resource recovery. Finally, socio-economic and policy-oriented studies are necessary to evaluate adoption barriers, farmer acceptance, and alignment with regulatory frameworks such as the Philippine Clean Water Act, ensuring that VHFS can be effectively implemented at scale.

Vetiver-based VHFS represents a viable, sustainable, and adaptable approach to wastewater management in backyard swine production. With continued research and system optimization, this technology has strong potential to bridge the gap between environmental compliance and practical application in resource-limited agricultural settings.

**Data Availability**

The data supporting this study are derived from previously published literature, reports, and publicly accessible sources cited throughout the manuscript. As a review paper, it does not generate primary datasets but instead synthesizes and analyzes existing findings from peer-reviewed journals, institutional publications, and regulatory documents. Therefore, no new or proprietary data were produced. All relevant information can be accessed through the references provided, ensuring transparency and enabling readers to verify and further explore the sources used in this study.

**Ethical Approval**

This study is a review of existing literature and did not involve any direct experimentation on human participants or animals; therefore, ethical approval was not required.

**Conflict of Interest**

The authors declare no conflicts of interest related to this study.

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