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Characterization of Household-Scale Pig Farming Wastewater and Evaluation of Treatment Efficiency Using Constructed Wetlands in Thanh Hoa Province, Vietnam

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ABSTRACT: Pig farming wastewater from small-scale household systems in Vietnam presents significant environmental challenges due to its high concentrations of organic matter, suspended solids, and nutrients. This study aimed to (i) characterize wastewater generated from household pig farms in Thanh Hoa Province and (ii) evaluate the treatment performance of a hybrid constructed wetland (HCW) system as a post-treatment stage following biogas digestion. A survey was conducted at 20 representative households, each raising 10–50 pigs. A pilot-scale HCW system, consisting of a subsurface flow constructed wetland (SSF CW) followed by a free-floating plants constructed wetland (FFP CW), was operated continuously for 100 days at a flow rate of 150 l/day. Results indicated that the influent wastewater remained highly polluted after biogas treatment, with COD, TSS, TN, and TP concentrations exceeding regulatory limits. The HCW system achieved average removal efficiencies of 80.8% for COD, 84.0% for TSS, 79.6% for TN, and 75.4% for TP. The final effluent quality consistently met QCVN 62-MT:2025/BTNMT (Column B). These findings demonstrate that the HCW system is an effective, low-cost, and sustainable solution for improving wastewater treatment efficiency in small-scale pig farming systems, thereby contributing to environmental protection and sustainable rural development.

KEYWORDS: Pig farming wastewater; small-scale household; constructed wetland; wastewater treatment; Vietnam.

1. Introduction

Vietnam is one of the leading countries in Asia in terms of pig production, with pork output ranking among the highest globally [1]. Thanh Hoa Province is among the regions with a high density of pig farming and played a significant role in supplying food to the Northern and North Central regions of the country [2]. However, alongside the expansion in scale and intensity of livestock production, the volume of wastewater generated increased substantially, exerting considerable pressure on soil, water, and air environments [3].

Pig farming wastewater typically contained high concentrations of organic pollutants (e.g., BOD, COD), suspended solids (TSS), nutrients (nitrogen and phosphorus), pathogenic microorganisms, and recalcitrant compounds [3,4]. In smallholder farming systems, wastewater treatment infrastructure remained rudimentary, often limited to biogas digesters or direct discharge into the environment [5,6]. This practice posed significant risks of surface and groundwater contamination, thereby threatening public health and ecosystem integrity [7,8].

In this context, the development of effective, low-cost, and locally appropriate wastewater treatment solutions for rural areas was of critical importance [9]. Constructed wetland technology had been widely studied and applied worldwide due to its capability to simultaneously remove multiple pollutants through integrated physical, chemical, and biological processes [10]. Notably, this system offered advantages such as simple operation, low capital and maintenance costs, and suitability for the socio-economic and technical conditions of small-scale livestock farmers [11].

Several studies had investigated the treatment of livestock wastewater using constructed wetlands in Vietnam. However, research focusing on specific local conditions, particularly in Thanh Hoa Province, remained limited [3,12]. Thanh Hoa Province had a tropical monsoon climate with favorable conditions for the application of constructed wetlands (CW). In addition, household-scale pig farms often had limited budgets for environmental treatment. CW technology was therefore a suitable solution for Thanh Hoa Province to control livestock wastewater quality, as its operating costs were up to ten times lower than those of physicochemical treatment technologies. Furthermore, the characteristics of smallholder pig farming wastewater were highly variable, necessitating site-specific assessment for the selection and design of appropriate treatment technologies.

Therefore, this study aimed to (i) evaluate the characteristics of wastewater generated from small-scale pig farming households in Thanh Hoa Province, and (ii) assess the treatment performance of constructed wetland systems with respect to key pollution parameters. The findings were expected to provide a scientific basis for proposing suitable wastewater management solutions, contributing to environmental pollution mitigation and the sustainable development of livestock production in the region.

2. Methodology

2.1. Wastewater sampling survey.

The study was conducted across 20 small-scale pig farming households (10–50 pigs per household) in Thanh Hoa Province (Figure 1). The selected households were representative of typical smallholder livestock production systems in the region. At each site, wastewater samples were collected at two locations: (i) the influent point of the treatment system (raw wastewater generated from livestock activities prior to treatment), and (ii) the effluent point (treated wastewater prior to discharge into the environment). In parallel with sample collection, a field survey was conducted to obtain relevant information, including farm scale and production practices; current status of wastewater generation and management; types of treatment technologies employed (e.g., biogas digesters, stabilization ponds, or absence of treatment); operational conditions of the treatment systems; and preliminary treatment performance based on field observations and available empirical data.

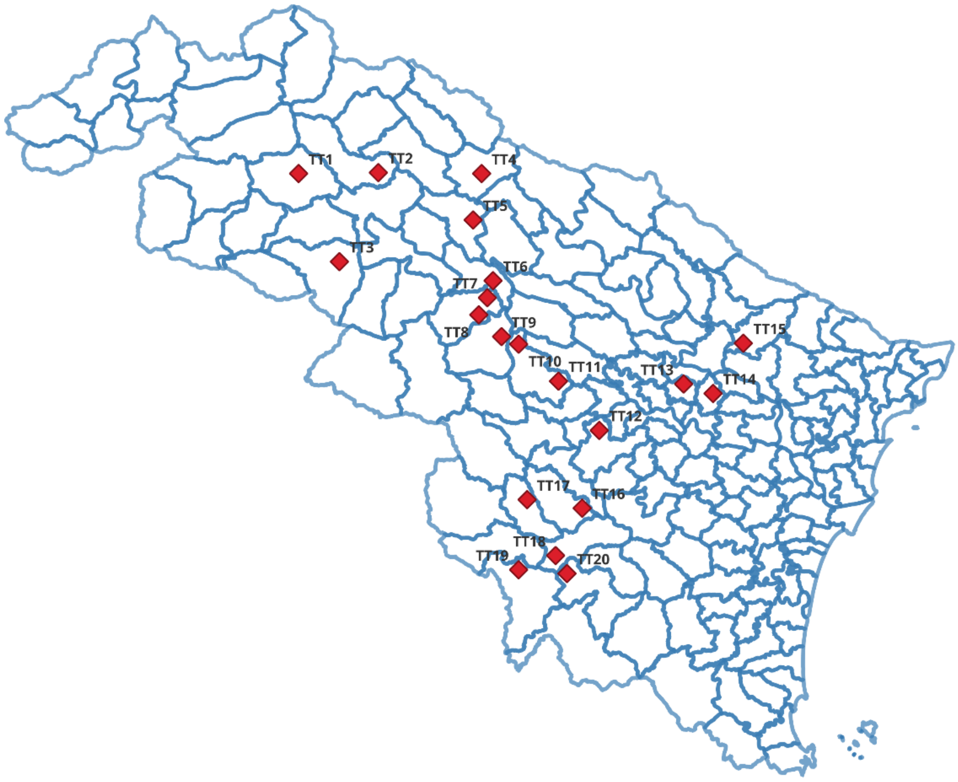

Figure 1. Locations of survey sites and pig farming wastewater sampling points in Thanh Hoa province.

2.2. Experimental setup.

The experimental system was installed at a household-scale pig farm in Thanh Hoa Province, Vietnam. The local climatic conditions during the experimental period included temperatures ranging from 28 to 33 °C, relative humidity from 80 to 88%, and sunshine duration from 10.3 to 11.6 hours per day. The hybrid constructed wetland (HCW) system was designed to include two treatment stages: (i) Subsurface Flow Constructed Wetlands (SSF CW) and (ii) Free Floating Plants Constructed Wetlands (FFP CW) (Figure 2). The SSF CW was designed as a vertical-flow unit with dimensions of 2 × 0.5 × 1 m (length × width × height), consisting of three filtration layers arranged from bottom to top: gravel, limestone, and sand. In this system, the uppermost layer consists of fine sand to facilitate plant root development; the second layer comprises limestone, which functions to neutralize acidity and provide a suitable substrate for microbial growth; and the bottom layer is composed of coarse stones to enhance water circulation and prevent clogging. The plant species used in the system are native to Thanh Hóa, and only healthy, carefully selected plants were employed. The plant species used in this unit was common reed (*Phragmites australis*), planted at a density of 45 plants/m². Effluent from the SSF CW was subsequently conveyed to the FFP CW unit for further treatment. The FFP CW unit had dimensions of 2 × 1 × 0.6 m (length × width × height), utilizing floating aquatic plants (*Cyperus alternifolius*) with approximately 50% surface coverage. The influent wastewater was collected from the effluent of a biogas digester at a pig farm in Thanh Hoa Province. Wastewater was continuously fed into the system using a dosing pump at a flow rate of 150 L/day. The experimental period lasted 100 days. Water samples were collected at 5-day intervals from the influent and effluent of each treatment stage to evaluate the treatment performance of the system.

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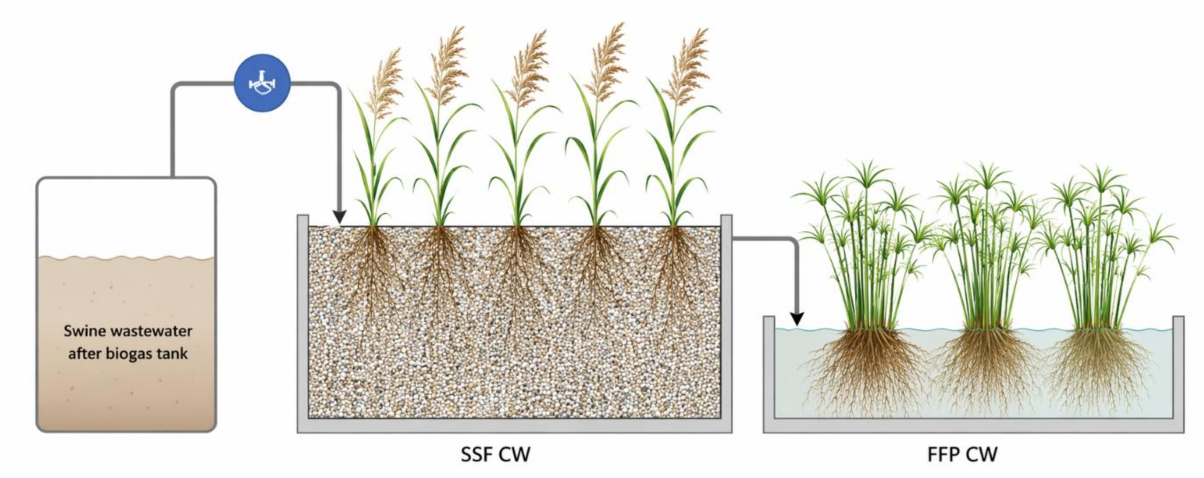

Figure 2. Experimental setup of the constructed wetland system.

2.3. Water quality analysis methods.

Wastewater quality parameters, including total suspended solids (TSS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP), were analyzed in accordance with corresponding Vietnamese Standards (TCVN), specifically: TSS following TCVN 6625:2000, COD following TCVN 6491:1999, TN following TCVN 6638:2000, and TP following TCVN 6202:2008.

3. Results and Discussion

3.1. Characteristics of pig farming wastewater.

Wastewater from small-scale pig farming households in Thanh Hoa Province was characterized by high pollution levels, with elevated concentrations of organic matter, suspended solids, and nutrients. Survey results indicated that influent COD and TSS reached 1824.6 ± 29.7 mg/l and 800.3 ± 18.6 mg/l, respectively, which were approximately 8–11 times higher than the permissible regulatory limits. Notably, total nitrogen (248.5 ± 11.4 mg/l) and total phosphorus (44.1 ± 4.6 mg/l) were also present at high levels, posing a significant risk of eutrophication in receiving water bodies (Table 1).

Table 1. Characteristics of wastewater from small-scale pig farms in Thanh Hoa province.

Parameter	Unit	Input	Biogas	QCVN 62:2025/BTNMT, Column B
pH	-	7.1±0,3	6.8±0,5	6-9
COD	mg/l	1824,6±29,7	421.5±26,2	150
TSS	mg/l	800,3±18.6	224,8±22,9	100
TN	mg/l	248.5±11.4	182.3±14,3	60
TP	mg/l	44,1±4,6	35,6±2,8	14

The survey further revealed that 100% of the households employed biogas digesters as the primary wastewater treatment system. However, the effluent from the biogas systems did not meet the requirements of QCVN 62-MT:2025/BTNMT (Column B). The quality of wastewater after biogas treatment still exceeded the permissible standards by 2–3 times. This indicated that, although biogas technology was an effective and appropriate primary treatment solution, it was insufficient to ensure adequate effluent quality [13]. The discharged wastewater could cause organic pollution in surrounding water bodies, leading to eutrophication and adverse impacts on aquatic ecosystems. Therefore, the integration of additional treatment technologies, such as constructed wetlands (CW), was necessary to enhance overall treatment performance, particularly for nutrient removal and residual pollutant reduction.

3.2. Treatment performance of the constructed wetland system.

3.2.1. TSS removal efficiency.

The average influent TSS concentration was 269.82 ± 24.27 mg/l, approximately 2.7 times higher than the permissible standard. Following treatment in the SSF CW system, suspended particles were effectively retained through sedimentation and filtration mechanisms [14]. As a result, TSS concentrations decreased to 96.28 ± 10.84 mg/l, corresponding to a removal efficiency of 64.1 ± 4.8%; however, the effluent quality at this stage did not consistently meet regulatory limits. The subsequent FFP CW stage further reduced TSS by 54.6 ± 9.3%. After the complete treatment process, TSS concentrations declined to 42.92 ± 5.87 mg/l, achieving an overall removal efficiency of 84.0 ± 2.3% and meeting the requirements of QCVN 62-MT:2025/BTNMT (Column B) (Figure 3).

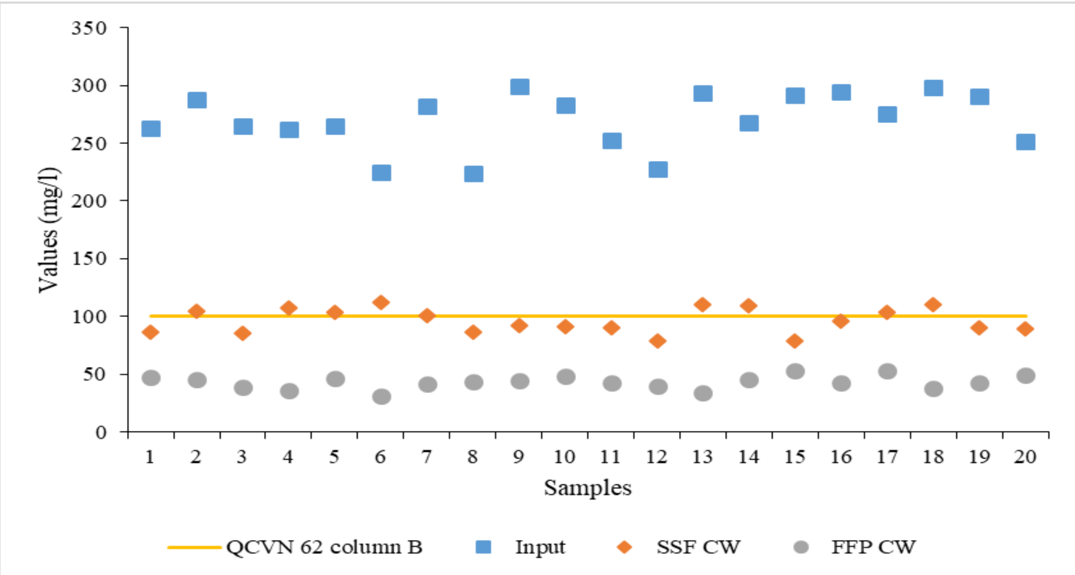

Figure 3. Changes in TSS concentrations before and after treatment throughout the experimental period.

3.2.2. COD removal efficiency.

The average influent COD concentration was 433.81 ± 37.17 mg/l, exceeding the permissible limit by nearly three times. After treatment in the SSF CW system, COD decreased to 176.03 ± 7.38 mg/l, corresponding to a removal efficiency of 59.2 ± 3.5%. Within the SSF CW unit, COD removal occurred through a combination of filtration, adsorption, and microbial biodegradation by biofilms attached to the media surfaces and plant root zones under anaerobic and anoxic conditions [3, 15]. However, COD concentrations after the SSF CW stage did not consistently meet the regulatory standard. The subsequent FFP CW unit further reduced COD concentrations to 83.43 ± 9.15 mg/l. The presence of floating aquatic plants contributed to oxygen transfer and partial uptake of dissolved organic matter [16]. The overall removal efficiency of the hybrid system reached 80.8 ± 1.3%, with final effluent COD concentrations complying with QCVN 62-MT:2025/BTNMT (Column B) (Figure 4).

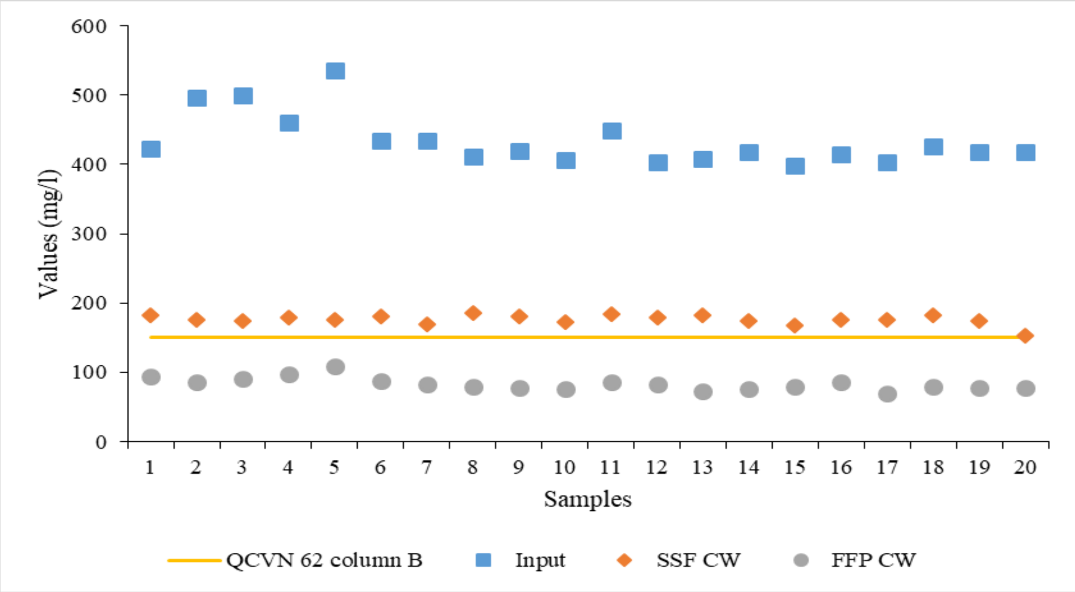

Figure 4. Changes in COD concentrations before and after treatment throughout the experimental period.

3.2.3. TN Removal efficiency.

The results demonstrate the high treatment efficiency of the HCW system. The average influent TN concentration was 190.63 ± 7.26 mg/l, which decreased to 81.81 ± 5.12 mg/l after passing through the SSF CW unit. In this stage, TN removal primarily occurred via nitrification–denitrification processes, along with partial uptake into plant biomass [17, 18]. However, TN concentrations at this stage still did not meet the permissible standard. The subsequent FFP CW unit further reduced TN concentrations to 38.93 ± 1.49 mg/L, corresponding to a removal efficiency of 52.3 ± 2.7%. In this stage, TN removal was mainly attributed to plant assimilation and microbial activity under aerobic conditions [16, 19]. The overall removal efficiency of the HCW system reached 79.6 ± 1.0%, with final effluent TN concentrations meeting the requirements of QCVN 62-MT:2025/BTNMT (Column B) (Figure 5).

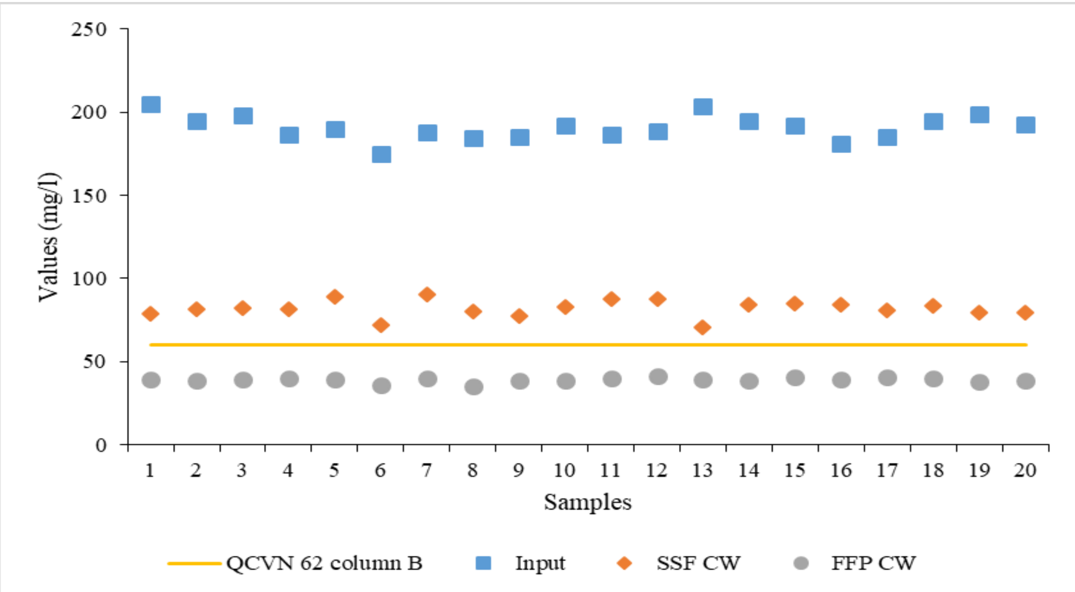

Figure 5. Changes in TN concentrations before and after treatment throughout the experimental period.

3.2.4. TP Removal efficiency.

The average influent TP concentration was 38.90 ± 1.20 mg/l, exceeding the permissible limit by more than 2.7 times. After treatment in the SSF CW unit, TP decreased to 19.15 ± 1.81 mg/l, corresponding to an average removal efficiency of 50.7 ± 4.9%. In the SSF CW system, phosphorus removal occurred through adsorption onto the media surfaces, precipitation with metal ions (particularly Ca^{2+} in the limestone layer), and accumulation in plant biomass and rhizosphere microorganisms [20, 21]. Additionally, mechanical filtration and retention of phosphorus-containing particles also contributed to TP reduction. Subsequently, the FFP CW unit further reduced TP concentrations to 9.55 ± 1.44 mg/l, achieving a removal efficiency of 49.6 ± 9.3%. In this stage, phosphorus removal was primarily driven by nutrient uptake by floating plants, assimilation into biomass, and sedimentation of suspended particles [19, 22]. The overall TP removal efficiency of the HCW system reached 75.4 ± 3.8%, demonstrating the synergistic performance of the hybrid system. Notably, TP concentrations in the treated effluent consistently remained below the limits specified in QCVN 62-MT:2025/BTNMT throughout the experimental period.

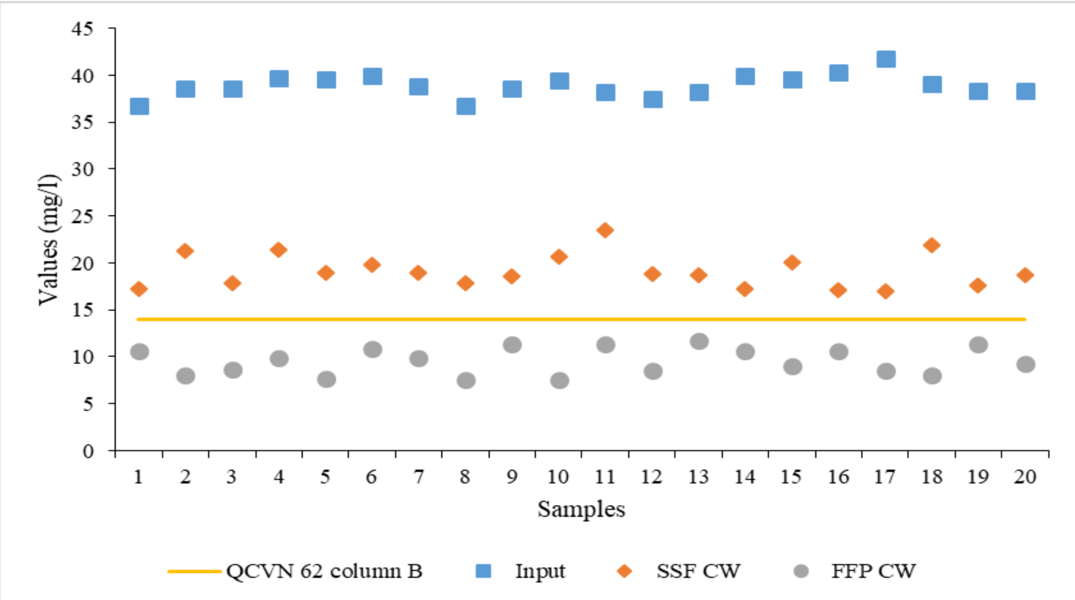

Figure 6. Changes in TP concentrations before and after treatment throughout the experimental period.

3.3. Discussion.

Wastewater from household-scale pig farms in Thanh Hoa Province represented a significant environmental concern due to its high pollutant concentrations. Although the pH of both influent and biogas effluent remained within the permissible range specified in QCVN 62:2025/BTNMT (Column B), COD, TSS, TN, and TP concentrations in the biogas effluent still exceeded the regulatory limits by approximately 2.25, 2.81, 3.04, and 2.54 times, respectively. The results indicated that the HCW system was highly effective in treating pig farming wastewater following biogas treatment, particularly for organic pollutants, suspended solids, and nutrients. Overall, the system achieved average removal efficiencies of 80.8 ± 1.3% for COD, 84.0 ± 2.3% for TSS, 79.6 ± 1.0% for TN, and 75.4 ± 3.8% for TP, demonstrating stable performance throughout the experimental period. These findings are consistent with previous studies, further confirming the effectiveness of constructed wetland technology in treating livestock wastewater [23].

The HCW system shows strong potential as a post-treatment solution for pig farming households in Thanh Hoa Province. With advantages such as low investment cost, simple operation, minimal technical requirements, and compatibility with rural land availability, this system can be widely implemented in small-scale farms to enhance wastewater treatment efficiency and mitigate local water pollution. In Vietnam, constructed wetlands have been widely studied and applied for treating various types of wastewater. However, this study still has certain limitations, including the relatively small experimental scale and limited operational duration, which may not fully capture the effects of local climatic conditions or the potential for performance improvement through the use of native plant species [17, 24].

In addition, climate change is increasingly affecting Vietnam. Rising temperatures, irregular rainfall patterns, prolonged droughts, and more frequent extreme weather events may significantly influence the performance and stability of CW systems [3,25]. These factors can affect hydraulic loading rates, pollutant removal processes, and plant growth dynamics, thereby necessitating further investigation into system resilience and adaptability under changing climatic conditions [21, 26].

Therefore, future studies should focus on evaluating system performance at larger scales and over longer operational periods, while also optimizing design parameters such as filter media and the selection of indigenous plant species. These research directions will contribute to strengthening the scientific basis and promoting the broader application of constructed wetland technology for pig farming wastewater treatment in Thanh Hoa and similar regions.

4. Conclusions

Wastewater from small-scale pig farming in Thanh Hoa Province remains highly polluted after biogas treatment and does not meet discharge standards. The HCW system demonstrated high and stable treatment efficiency, achieving removal rates of 80.8% (COD), 84.0% (TSS), 79.6% (TN), and 75.4% (TP), with effluent quality meeting QCVN 62-MT:2025/BTNMT (Column B). These results highlight the potential of HCW as a low-cost, effective, and sustainable post-treatment solution for small-scale livestock systems. Further studies should focus on system optimization and large-scale application.

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Author Contribution

Bui Thi Van Nga: Conceptualization, Validation, Writing; Hoang Quoc Anh: Writing – review & editing; Le Duc Anh Tuan: Writing – review & editing; Chao Rong: Investigation, Writing, Writing – review & editing.

Competing Interest

The authors declare no competing interests.

References

[1] OECD-FAO Agricultural Outlook 2022–2031. In, Eds.; Book OECD-FAO Agricultural Outlook 2022–2031, 3rd ed.; OECD Publishing: Paris, France.

[2] Tổng cục Thống kê (2025). Niên giám thống kê Việt Nam năm 2024. In Niên giám thống kê Việt Nam năm 2024; Nhà xuất bản Thống kê, Ed.; Hà Nội: Vietnam.

[3] Van Thanh, N.; Anh, B.T.K.; Phuong, N.M.; Ha, N.T.H.; Hang, N.T.A.; Mai, N.T.; Binh, N.T.; Cong, L.T.N.; Thuy, P.T.; Toan, V.N. (2025). Insights of a medium-scale hybrid constructed wetland system operation for swine wastewater in Northern Vietnam: Influence of tropical monsoon climate and operational duration. *Ecological Engineering*, *221*, 107772. https://doi.org/10.1016/j.ecoleng.2025.107772.

[4] Anh, B.T.K.; Van Thanh, N.; Phuong, N.M.; Ha, N.T.H.; Yen, N.H.; Lap, B.Q.; Kim, D.D. (2020). Selection of suitable filter materials for horizontal subsurface flow constructed wetland treating swine wastewater. *Water, Air, & Soil Pollution*, *231*, 88. https://doi.org/10.1007/s11270-020-4449-6.

[5] Wastewater treatment efficiency of small and large-scale pig farms in Vietnam. (accessed on 1 February 2026) Available online: https://api.lib.kyushu-u.ac.jp/opac_download_md/4486561/6602_p291.pdf.

[6] Dinh, T.X.; Cassou, E.; Cao, B.T. (2017). An overview of agricultural pollution in Vietnam: The livestock sector. An Overview of Agricultural Pollution in Vietnam: The Livestock Sector; World Bank: Washington, DC, USA.

[7] Thi To Uyen, T.; Trong Tin, N.; Thi Minh Hang, T.; Quoc Dung, N.; Manh Khai, N. (2025). Evaluate swine wastewater digestate for nutrient recovery. *VNU Journal of Science: Earth and Environmental Sciences*, *41*. https://dx.doi.org/10.25073/2588-1094/vnuees.5416.

[8] Bui, T.K.A.; Nguyen, V.T.; Pham, T.G.; Dang, D.K. (2019). Study on using reed (Phragmites australis) and water spinach (Ipomoea aquatica) for piggery wastewater treatment after biogas process by constructed wetland. *Tạp chí Sinh học*, *41*, 327–335. https://doi.org/10.15625/0866-7160/v41n2se1&2se2.14184.

[9] Anh, B.T.K.; Thanh, N.V.; Kim, D.D.; Ngoc, D.Q.; Ha, N.T.H.; Phuong, N.M.; Thuy, P.T. (2025). Potential and strategies for implementing constructed wetland technology to mitigate water pollution in Hanoi's lakes and ponds, Vietnam. *Vietnam Journal of Science and Technology*, *63*, 849–863. https://doi.org/10.15625/2525-2518/22558.

[10] Thanh, N.V.; Hai, D.T.; Thuy, N.T.T.; Anh, B.T.K.; Khanh, T.V. (2022). Evaluating the treatment efficiency of the subsurface constructed wetlands system and free floating plants system for wastewater from noodle handicraft village in Hiep Hoa commune. *TNU Journal of Science and Technology*, *227*, 367–375. https://doi.org/10.34238/tnu-jst.5926.

[11] Sarmento, A.P.; Borges, A.C.; Matos, A.T. (2012). Evaluation of vertical-flow constructed wetlands for swine wastewater treatment. *Water, Air, & Soil Pollution*, *223*, 1065–1071. https://doi.org/10.1007/s11270-011-0924-4.

[12] Anh, B.T.K.; Thanh, N.V.; Chuyen, N.H.; Phuong, N.M.; Kim, D.D. (2020). Treatment efficiency of piggery wastewater by surface and horizontal subsurface flow constructed wetlands. *Vietnam Journal of Science and Technology*, *58*, 84–92. https://doi.org/10.15625/2525-2518/58/3A/14272.

[13] Shelef, O.; Gross, A.; Rachmilevitch, S. (2013). Role of plants in a constructed wetland: Current and new perspectives. *Water*, *5*, 405–419. https://doi.org/10.3390/w5020405.

[14] Nguyen, V.T.; Pham, T.G.; Bui, T.K.A.; Nguyen, T.T.T.; Dang, D.K. (2025). Efficiency of constructed wetlands with indigenous umbrella sedge for rural domestic wastewater treatment in Northern Vietnam. *Tropical Environmental Biology and Technology*, *3*, 123–132. https://doi.org/10.53623/tebt.v3i2.850.

[15] Binh, N.T.; Kim Anh, B.T.; Thanh, N.V.; Kim, D.D.; Phuong, N.M. (2023). The influence of pollutants on plant growth and treatment efficiency of horizontally constructed wetlands. *Vietnam*

Journal of Science, Technology and Engineering, *65*, 42–46. https://doi.org/10.31276/VJSTE.65(2).42-46.
[16] Wu, H.; Wang, R.; Yan, P.; Wu, S.; Chen, Z.; Zhao, Y.; et al. (2023). Constructed wetlands for pollution control. *Nature Reviews Earth & Environment*, *4*, 218–234. https://doi.org/10.1038/s43017-023-00395-z.
[17] Anh, T.K.B.; Nguyen, V.T.; Nguyen, H.C.; Bui, Q.L. (2019). Analysis and evaluation: applicability of constructed wetland for piggery wastewater treatment after biogas process. *Journal of Water Resources and Environmental Engineering*, *66*, 10–15.
[18] Thanh, N.V.; Thuong Giang, P.; Anh, B.T.K.; Thuy, N.T.T. (2025). Evaluation of treatment performance over time of constructed wetlands for wastewater from rice noodle handicraft village after biogas process. *Sustainable Environmental Insight*, *2*, 113–123. https://doi.org/10.53623/sein.v2i2.796.
[19] Phuong, N.M.; Hai, D.T.; Thanh, N.V.; Anh, B.T.K. (2022). Iron and manganese removal from wastewater by constructed wetlands planted with Caladium bicolor. *VNU Journal of Science: Earth and Environmental Sciences*, *38*. https://doi.org/10.25073/2588-1094/vnuees.4861.
[20] García-Valero, A.; Acosta, J.A.; Faz, Á.; Gómez-López, M.D.; Carmona, D.M.; et al. (2024). Swine wastewater treatment system using constructed wetlands connected in series. *Agronomy*, *14*, 143. https://doi.org/10.3390/agronomy14010143.
[21] Thanh, N.V.; Anh, B.T.K.; Thuy, N.T.T.; Yen, N.H.; Chuyen, N.H.; Kim, D.D. (2024). Study filter materials for vertical subsurface flow constructed wetland to treat wastewater from Da Mai noodle handicraft village. *VNU Journal of Science: Earth and Environmental Sciences*, *40*, 93–104. https://doi.org/10.25073/2588-1094/vnuees.5078.
[22] Thuy, N.T.T.; Thanh, N.V.; Khai, B.D.; Manh, D.N.; Quynh, Q.T.; et al. (2026). The effectiveness of portable heat patch in protecting the health of military personnel operating in cold conditions in Northern Vietnam. *Journal of Tropical Science and Engineering*, *1*, 2–16. https://doi.org/10.58334/jtse.vol.001.792.
[23] Anh, B.T.K.; Thanh, N.V.; Phuong, N.M.; Ha, N.T.H.; Duong, N.T.; Kim, D.D.; Yen, N.H.; Chuyen, N.H. (2024). Selection of suitable filter materials for subsurface flow constructed wetland systems for wastewater treatment in rice noodle handicraft village. *Vietnam Journal of Science and Technology*. https://doi.org/10.15625/2525-2518/21065.