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How do contract pig farms impact the quality of the water environment? Evidence from Hanoi, Vietnam

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Abstract

The trend of developing intensive livestock farming is becoming increasingly common worldwide. This has a significant impact on environmental quality, especially water quality. This study was carried out in Hanoi to assess the impact of contract farming (CF) in pigs on the water environment. The aim of this study is to demonstrate the actual impact of CFs on surrounding surface and groundwater. A total of 70 contract pig farms were investigated. In addition, wastewater, surface water, and groundwater samples were collected and analyzed for quality parameters. The results showed that contract pig farms had implemented biogas in combination with other treatment methods such as waste separation, composting, and biological ponds/lakes. However, the wastewater discharged from the farms did not meet the standards of QCVN 62:2025/BTNMT. The study also indicated that surface water surrounding the farms was polluted by ammonium (NH_4^+), nitrite, and phosphate ions in both the dry and rainy seasons. The water quality index was 63.97 points in the dry season and 67.85 points in the rainy season, indicating average water quality. Conversely, groundwater at pig farms remains largely unaffected and in good condition. The average concentrations of both NH_4^+ and nitrate ion were lower than the permissible limits set by QCVN 09:2023/BTNMT. At the same time, the comprehensive pollution index values for groundwater were 0.16 and 0.15 in the dry and rainy seasons, respectively, indicating that the water quality consistently remained clean. Promoting CFs is necessary, but it must be accompanied by improvements in waste treatment systems and stricter regulations controlling emissions.

Keywords: Contract pig farms; Hanoi; Pollution; Groundwater; Surface water

1. Introduction

Water is the foundation of life on Earth and plays a vital role in ecosystems. Freshwater is a fundamental resource that supports development, food security, livelihoods, economic growth, and environmental sustainability worldwide.[1-3] However, this resource is increasingly overexploited and burdened with waste from production activities, particularly agriculture and livestock farming. Inadequate water resource management has led to declining water quality, increased pollution, and water scarcity. This issue has emerged as a major global environmental concern, especially in developing countries where agriculture and livestock farming dominate the economy while waste treatment systems remain limited.[4-6] In the livestock sector, in 2006, the Food and Agriculture Organization of the United Nations[4] reported that drinking and service water for animals accounts for approximately 0.6% of global freshwater consumption, most of which is subsequently discharged into the environment as manure and wastewater rich in nutrients (nitrogen, phosphorus, potassium), pharmaceutical residues, and pathogens. This poses serious risks to aquatic environments, particularly in pig production. Numerous studies worldwide have shown that livestock waste contains high concentrations of nutrients and microorganisms, specifically chemical oxygen demand (COD) ranging from 1,000 to 1,500 mg/L; total nitrogen (TN) ranging from 100 to 2,100 mg/L; and total phosphorus (TP) ranging from 20 to 350 mg/L, thereby potentially causing rapid water pollution if not strictly controlled.[7-9] Therefore, in high-density livestock farming areas, water bodies are often severely affected, as reported by Li *et al.*[10] in their study of the pollution status of major river basins in China. In addition, concentrated pig farming poses a risk of groundwater pollution through the infiltration of pollutants from contaminated surface water or from untreated waste into the soil and groundwater. This issue has been confirmed by Govarchin *et al.*[11] and Pedrozo-Acuña *et al.*[12] in Mexico.

In Vietnam, the impact of livestock farming on surface and groundwater has been demonstrated by Ho *et al.*[13] in Hai Duong (now part of Hai Phong City). This issue continues to be reported in studies on water pollution levels at pig farms in Hung Yen[14] and Hanoi.[15] These studies have provided compelling evidence of the negative impacts of intensive pig farming on surface and groundwater quality.[13-16] Specifically, pig farms designed according to the Garden–Fish Pond and Pigsty and Fish Pond–Pigsty models have a lower impact on the aquatic environment compared to pig farms designed according to the Pigsty–Garden and Pigsty models. These studies focus on clarifying the levels of surface and groundwater pollution in livestock farming areas. In studies by Ho *et al.*,[13,14] the level of water pollution in household and farm-scale livestock areas was only assessed through individual monitoring parameters and was not evaluated based on surface water quality index (WQI) and comprehensive pollution index (CPI); therefore, a complete assessment of the pollution level could not be provided. Subsequent studies by Cao *et al.*[15] and Ho *et al.*[16] used WQI and CPI indices to comprehensively analyze water pollution levels in livestock farming areas in Vietnam. These studies focused on identifying pollution and comparing pollution levels in livestock farms according to different pig farming systems (pig farm structures). However, none of the above studies have addressed the environmental impact on water quality from livestock farms operating under organized production models (contract farming [CF] or non-contract farming [NCF]). This is a research gap that needs to be addressed, as Vietnamese pig farming practices are shifting from traditional farmer-based farming to CF between farmers and large livestock companies/corporations. When considering production organization methods, pig farms in Vietnam currently operate in two main forms: (i) traditional farming without contracts (NCF); and (ii) CF, in which farmers sign economic contracts with large companies and corporations such as Vietnam CP group, De Heus, Japfa Comfeed, BAF, GreenFeed, and Dabaco.[17,18] In this context, contract pig farming is understood as "a fixed-term contractual agreement between a farmer and a company, agreed upon orally or in writing before the commencement of production, providing resources (with or without specifying the value of the funding) to the farmer and/or specifying one or more production conditions, in addition to one or more marketing conditions, for the production of pigs on land owned or controlled by the farmer, which is non-transferable and grants the company, and not the farmer, exclusive and legal ownership rights to the production process."[19,20] CF of pigs brings many benefits to farmers such as: (i) convenient access to the product consumption market; (ii) reduced initial investment capital; (iii) access to information on market prices, techniques, management skills, investment capital, veterinary services, and agricultural extension. In addition, CF helps farmers improve the quality of their livestock by providing them with better breeds from businesses.[21] For businesses, this will ensure a stable supply of goods, guarantee the quality of inputs and outputs, control the entire production process and delivery times, and avoid dealing with environmental pollution from livestock farming.[17] In the current context, CF is developing rapidly in Vietnam, especially in medium- and large-scale farms associated with foreign direct investment enterprises (CP, Japfa, CJ, and Dabaco), thanks to guaranteed stable

output, technical and veterinary support, and investment in more systematic waste treatment systems. Conversely, NCF remains prevalent on small-scale livestock farms, which are limited in capital and treatment capacity, thereby posing a higher risk of water pollution.[17] In addition, contract pig farms help improve water and electricity efficiency,[22] thereby contributing to improved technical efficiency[18] and ecological efficiency.[23] However, there is no conclusive evidence that CF has a lower impact on water environments compared to NFC. This is a major gap that needs to be addressed to help livestock policymakers decide whether to promote CF in pigs. This research was conducted with the aim of achieving specific objectives such as:

(i) Assessing the environmental impact of contract pig farms on surface and groundwater quality;
(ii) Comparing the level of impact on the aquatic environment of CFs versus NCFs;
(iii) Proposing recommendations for regulatory agencies to reduce the impact of pig farms on water environments.

2. Study areas and research method

2.1. Study area

This study was conducted in the suburban areas of Hanoi, Vietnam's capital. Located in the northwest of the Red River Delta, Hanoi covers an area of 3,359.8 km^2 and had a population of 8.7 million in 2024. Hanoi has a large agricultural land area of 196.6 thousand hectares, with approximately 4.4 million people living in rural areas (accounting for 50.9% of the city's total population.[24] Located in the center of the Red River Delta, Hanoi's terrain is relatively flat, with an average elevation of 5 m–20 m above sea level. Hanoi's climate is a tropical monsoon climate, with two main seasons: the rainy season (April to October) and the dry season (November to March); the average annual temperature is 23.6 °C (summer temperatures above 27 °C, winter temperatures around 22 °C); and the average annual rainfall is approximately 1,500–1,900 mm. Overall, the Hanoi area has favorable natural conditions for agricultural activities, especially pig farming.

The suburbs of Hanoi City comprise 16 areas: Ba Vi, Thach That, Chuong My, Ung Hoa, Phu Xuyen, Thanh Oai, Thuong Tin, Gia Lam, Dong Anh, Soc Son, Son Tay, Phuc Tho, My Duc, Quoc Oai, Me Linh, and Dan Phuong (Figure 1), and is now reorganized into 32 communes after the formation of a two-tiered government. These areas rank third nationwide in total pig population with 1.28 million pigs and a production output of 261.7 thousand tons per year. The city also has the highest number of pig farms nationwide, with 2,313 farms, including 232 medium- and large-scale farms operating under CF arrangements. CF accounts for approximately 51% of Hanoi's total pig population.[24] Contract pig farms are defined as farms with signed contracts with large livestock companies or corporations. Most contract pig farms are medium- to large-scale; the impact of these contract farms on environmental media, especially water quality, warrants particular attention.

2.2. Methodologies and methods

2.2.1. Methodology

To assess the impact of CFs on the aquatic environment (surface water and groundwater), we selected 100 representative pig farms in Hanoi for survey and sampling. This included 70 CFs (study subjects) and 30 NCFs (control group). The pig farms were selected based on advice from the Hanoi Department of Agriculture and Environment to ensure representativeness in terms of scale and spatial distribution. The production characteristics, waste management, and actual impacts of the two groups of CF and NCF were compared to identify differences in their impacts, as per **Equation 1**.

$$\Delta I = I_{CF} - I_{NCF} \quad (1)$$

where ΔI stands for the difference in impact between CF and NCF; I_{CF} stands for the impact of the CF; I_{NCF} stands for the impact of the NCF.

The research framework is illustrated in Figure 2. Accordingly, the main contents of the research include: (i) investigate the production characteristics and waste management practices of pig farms; (ii) collect samples of wastewater in the effluent; surface water, and groundwater in areas affected by wastewater generated from pig farms; (iii) analyze and assess water quality through comparison with environmental standards; (iv) calculate WQI and CPI indices; and (v) demonstrate the practical impacts of the CF by comparing them to the NCF.

2.2.2. Secondary data collection method

Information on natural conditions, socio-economic factors, pig farming development, and environmental protection in pig farming was collected from the Hanoi Department of Agriculture and Environment, the People's Committees of suburban communes in Hanoi, and other relevant agencies and departments.

2.2.3. Questionnaire survey method

The Hanoi area has a total of 2,312 pig farms. Of these, 232 farms have contracts (10% of the total), mainly large-scale farms (>1,500 pigs/year) and medium-scale farms

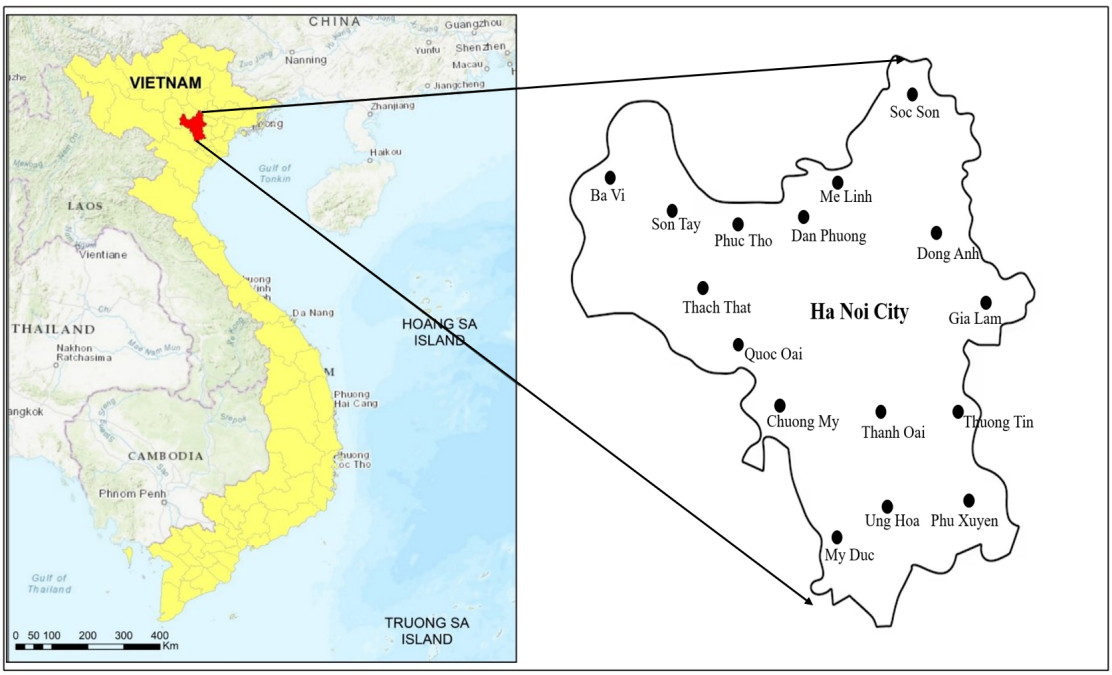

Figure 1. Geographical locations of the study areas in Vietnam

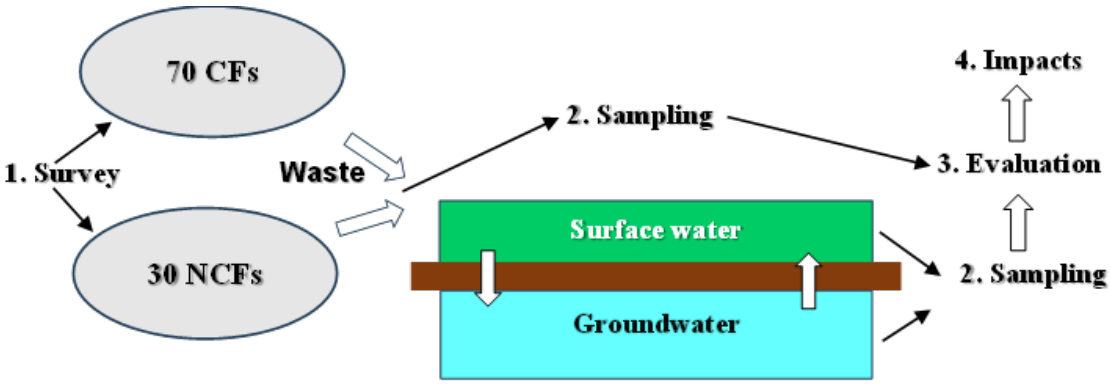

Figure 2. Research framework illustrating the study components
Abbreviations: CF: Contract farming; NCF: Non-contract farming.

(raising 500–1,500 pigs/farm). Based on the list of CFs, we selected 70 farms across two scales (large and medium; 35 farms each) to conduct the investigation. The farms were selected in accordance with the Department of Agriculture and Environment guidelines to ensure an even spatial distribution, with 3–5 farms surveyed in each area. A total of 16 suburban areas in Hanoi were investigated and surveyed (Figure 1). Similarly, in each survey area, 1–2 large- or medium-sized of the NCFs were selected as controls. As a result, we selected 100 representative pig farms in the suburban areas of Hanoi to collect primary data through a questionnaire survey. Of these, 70 CFs were selected as the main study subjects, and 30 NCFs were selected as the control group. The investigation was conducted through direct interviews with farm owners using a structured questionnaire. The selection of farms for the survey was made in consultation with the Hanoi Department of Agriculture and Environment to ensure the representativeness of the farms in terms of both size and spatial distribution.

2.2.4. Water sampling methods

To assess the effectiveness of wastewater treatment at each farm, one effluent sample from the treatment system was

collected for analysis. A total of 100 wastewater samples were collected from CFs (70 samples) and NCFs (30 samples) at the end of 2024. The parameters analyzed included pH, five-day biochemical oxygen demand (BOD_5), COD, total suspended solids (TSS), TN, TP, and coliform (Table 1).

A total of 100 groundwater samples (one sample per pig farm) were collected from the wells currently in use at the CF (70 samples) and NCF (30 samples), with well depths ranging from 10 to 20 m. Samples were collected in two phases: during the rainy season (2024) and the dry season (2025). The water quality parameters analyzed included: pH, electrical conductivity (EC), ammonia (NH_4^+), and nitrate (NO_3^-; Table 1).

The surface water quality data were obtained from the Hanoi Department of Agriculture and Environment's 2024 monitoring results, including two monitoring periods, the dry season and the rainy season. These monitoring locations are part of the water environment monitoring network in key pig farming areas of Hanoi city. We screened and selected water sample monitoring locations within the impact area of the CFs and NCFs based on the initial study design. The observational data were collected at the exact time the research was conducted. This process aims to reduce project costs while ensuring that the research objectives are met. A total of 72 monitoring locations have had their data collected. Of these, 30 locations were in ponds, lakes, and streams affected by wastewater from contracted pig farms, and 42 locations were in ponds, lakes, and streams in the area affected by wastewater from non-contracted pig farms. The parameters monitored included pH, temperature, dissolved oxygen (DO), BOD_5, COD, NH_4^+, nitrite (NO_2^-), phosphate (PO_4^{3-}), TSS, and coliform (Table 1).

2.2.5. Water analysis methods

The specific analysis methods for each wastewater, surface water, and groundwater quality parameter are presented in Table 2.

2.2.6. Impact assessment methods

Comparison with national standards was conducted to assess the impact of contract pig farms on water quality. The measured wastewater, surface water, and groundwater quality parameters were compared with the current Vietnamese national environmental standards as follows:

- Wastewater samples were compared with QCVN 62:2025/BTNMT–National Technical Regulation on Livestock Wastewater.[25]
- Surface water samples were compared with QCVN 08:2023/BTNMT–National Technical Regulation on Surface Water Quality.[26]
- Groundwater samples were compared with QCVN 09:2023/BTNMT–National Technical Regulation on Groundwater Quality.[26]

A comprehensive pollution index was used to assess the pollution level of a water body based on water-monitoring parameters.[27-30] The formula for calculating CPI is as follows:

$$CPI = \frac{1}{n}\sum_{i=1}^{n} \mathrm{PIi} \quad (2)$$

$$\mathrm{PI} = \frac{Ci}{Si} \quad (3)$$

Table 1. Information on the number of water samples and analytical parameters

No	Water sample type	CF	NCF	Monitored parameters
1	Wastewater	70	30	pH, BOD_5, COD, TSS, TN, TP, and coliform
	Groundwater	140	60	
2	Rainy season	70	30	pH, EC, NH_4^+, and NO_3^-
	Dry season	70	30	
	Surface water[a]	60	84	
3	Rainy season	30	42	pH, temperature, DO, BOD_5, COD, NH_4^+, NO_2^-, PO_4^{3-}, TSS, and coliform
	Dry season	30	42	

Note: [a] Data are inherited from the Hanoi Department of Agriculture and Environment.
Abbreviations: BOD_5: five-day biochemical oxygen demand; CF: Contract farming; COD: Chemical oxygen demand; DO: Dissolved oxygen; EC: Electrical conductivity; NCF: Non-contract farming; NH_4^+: Ammonia; NO_2^-: Nitrite ion; NO_3^-: Nitrate; PO_4^{3-}: Phosphate ion; TN: Total nitrogen; TP: Total phosphorus; TSS: Total suspended solids.

Table 2. Methods for analyzing water quality parameters

Parameter	Symbol	Analytical method
pH	–	TCVN 6492:2011
Temperature	°T	Measured using a portable meter in the field
Dissolved oxygen	DO	TCVN 7325:2016
Electrical conductivity	EC	Measured using a portable meter in the field
Biochemical oxygen demand	BOD_5	TCVN 6001-1:2008
Chemical oxygen demand	COD	TCVN 6491:1999
Total suspended solids	TSS	TCVN 6625:2000
Total nitrogen	T-N	TCVN 6638:2000
Ammonium	NH_4^+	TCVN 6660:2000
Nitrate	NO_3^-	TCVN 6180:1996
Nitrite	NO_2^-	TCVN 6494-1:2011
Total phosphorus	T-P	TCVN 6202:2008
Phosphate	PO_4^{3-}	TCVN 6494-1:2011
Coliforms	–	TCVN 6187-2:1996

where n is the number of water-monitoring parameters; PI_i is the pollution index of the ith parameter, calculated by **Equation 3**. In **Equation 3**, Ci is the concentration of parameter i in the water body; Si is the allowable limit of parameter i specified in water environmental regulations. CPI is rated on a scale described in Table 3.

Table 3. Rating scale for comprehensive pollution index (CPI)

No	CPI	
	Scores	Pollution level
1	0–0.2	Clean
2	0.21–0.40	Sub clean
3	0.41–1.00	Slightly polluted
4	1.01–2.00	Medium polluted
5	≥2.0	Heavily polluted

In this study, the CPI was calculated only for groundwater based on two parameters: NH_4^+ and NO_3^-.

The WQI was calculated in accordance with Decision No. 1460/2019/QD-TCMT that applied to surface water.[31] The specific calculation formula is as follows:

$$WQI = \frac{WQI_I}{100} \times \frac{\left(\prod_{i=1}^{n} WQI_{II}\right)^{1/n}}{100} \times \frac{\left(\prod_{i=1}^{m} WQI_{III}\right)^{1/n}}{100} \times \left[\frac{1}{k}\sum_{i=1}^{k} WQI_{IV} X \frac{1}{l}\sum_{i=1}^{l} WQI_V\right]^{1/2} \quad (4)$$

where:

- WQI_I: Calculation result for Group I parameters: pH;
- WQI_{II}: Calculation result for Group II parameters (plant protection-related parameters): not considered in this study;
- WQI_{III}: Calculation results for Group III parameters (heavy metal parameters): not considered in this study;
- WQI_V: Calculation results for Group IV parameters (organic and nutrient parameters): includes DO, BOD_5, COD, NH_4^+, NO_3^-, NO_2^-, and PO_4^{3-};
- WQI_V: Calculation results for Group V parameters (microbiological parameters): calculation with the coliform parameter.

The WQI index was classified using a scale with symbols and colors for water quality assessment (Table 4).

Table 4. Water quality assessment scale using water quality index (WQI) score

No.	WQI range	Water quality	Color
1	91–100	Very good	Light blue
2	76–90	Good	Green
3	51–75	Moderate	Yellow
4	26–50	Poor	Orange
5	10–25	Very poor	Red
6	< 10	Heavily polluted	Brown

2.2.7. Data analysis method

Excel was used to conduct descriptive statistical analyses and *t*-tests for livestock characteristics and water quality parameters at significance levels of 1%, 5%, and 10%.

3. Results

3.1. Production characteristics of contract pig farms

3.1.1. Production Characteristics

The results of the survey on the basic characteristics of CFs and NCFs in the study area are shown in Table 5. Accordingly, the average area of the farms was 11,975 m^2, of which 43.47% was allocated for livestock housing; the proportion of land area allocated for environmental treatment activities was relatively high, accounting for 51% (5,814 m^2/farm). The total number of pigs raised on the farms exceeded 2,600 pigs/farm, which was classified as a medium-scale operation. Overall, contract pig farms operated on a larger scale than the average farm (70% of Hanoi's pig farms being small-scale farms raising 500–1,000 pigs).[32] These farms also allocated up to 51% of their land area to waste treatment and environmental facilities (Table 5), indicating considerable attention to environmental management,

The results in Table 5 showed that CFs had a clear advantage in land area, scale and production output, stocking density, labor structure and costs, and farm investment costs compared to NCFs, with a high statistical significance level of 1% ($p < 0.01$). This demonstrated the investment in intensive, highly specialized development and scientific organization of the contracted livestock farms to achieve high production efficiency and economic benefits. At the same time, CFs showed greater interest and allocated larger areas on their farms for environmental treatment systems (statistically significant at the 1% and 5% levels). Conversely, indicators reflecting land use structure within the farm (ratio of barn area to total farm area and ratio of environmental treatment area to total farm area) and farm operating costs (seed, depreciation, and other expenses) did not show statistically significant differences between CFs and NCFs.

3.1.2. Current waste management status

Currently, the main waste treatment technology used by farms is biogas digesters combined with other treatment methods, such as manure separation (solid manure collection or mechanical separation), composting, and using biological ponds/biological filter beds to further treat wastewater after biogas treatment prior to discharge. The general waste treatment system for CFs in the study area is illustrated in Figure 3.

To clearly illustrate the differences in waste management and treatment methods at pig farms, this study compared the waste treatment characteristics between two groups of CFs and NCFs. For the qualitative comparisons, Fisher's exact test, the Chi-square test, and the *t*-test were used to identify statistically significant differences between the two groups in most variables related to technology and waste treatment methods, as presented in Table 6.

Table 6 shows that, with respect to the type of treatment facility, none of the CFs used only biogas or biogas combined with biological ponds. Instead, 38.6% of farms used biogas–settling tanks and 61.4% used biogas–settling tanks–biological ponds. Conversely, NCFs showed greater diversity in the application of biogas models and ancillary facilities, with farms applying pure biogas, biogas combined with biological ponds, and biogas combined with settling tanks and biological ponds, each accounting for approximately 30.0%, while only 10.0% of farms applied biogas systems combined with settling tanks. This indicates that farms with compliant contracts are more likely to invest in standardized wastewater treatment systems.

Regarding waste separation practices, the differences between the two groups of farms were clearly evident. Only 24.3% of CFs performed waste separation, while as many as 96.7% of NCFs separated waste before introducing it into the treatment system. Notably, although the CFs group had less waste separation, they had a higher waste reuse rate of 48.6% compared to 46.7% for the NCFs group.

In summary, the differences in waste management and treatment between CFs and NCFs were associated with the binding requirements imposed by livestock enterprises during the signing and implementation of livestock contracts, as well as compliance with environmental protection laws and regulations throughout the farming process. The waste treatment systems of CFs were generally

Table 5. Basic characteristics of CFs and NCFs in the study area

Indicators	Unit	CFs (n = 70)	NCFs (n = 30)	Difference
		Mean	Mean	p-value
Farm area	m^2	11,975	6,175	7.25×10^{-5}***
Pig pen area	m^2	4,009	1,323	1.26×10^{-10}***
Environmental treatment area	m^2	5,814	3,208	0.01***
Ratio of livestock pen area to total area	%	4.47	34.64	0.17
Ratio of environmental treatment area to total area	%	51.29	40.34	0.08*
Total number of pigs raised	Pigs	2,642	821	2.36×10^{-11}***
Pig density on the farm	Pigs/m^2	0.51	0.23	3.53×10^{-7}***
Average number of pigs per pen area	Pigs/m^2	0.70	0.66	8.31×10^{-7}***
Environmental treatment area per pig	m^2/pig	2.70	6.15	0.031**
Total pig production per litter	Tons/litter	272.97	95.34	9.51×10^{-10}***
Number of family workers	People/farms	0.34	1.10	0.52***
Number of hired workers	People/farms	3.27	0.80	0.00***
Farm investment costs	Billion VND	9.37	3.84	3.13×10^{-8}***
Labor costs	million VND/ton	0.20	1.00	3.32×10^{-5}***
Cost of breeding pigs	million VND/ton	16.97	17.90	0.21
Depreciation of livestock facilities	million VND/ton	0.52	0.58	0.04
Other costs	million VND/ton	3.78	3.52	0.59

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
Abbreviations: CF: Contract farming; NCF: Non-contract farming.

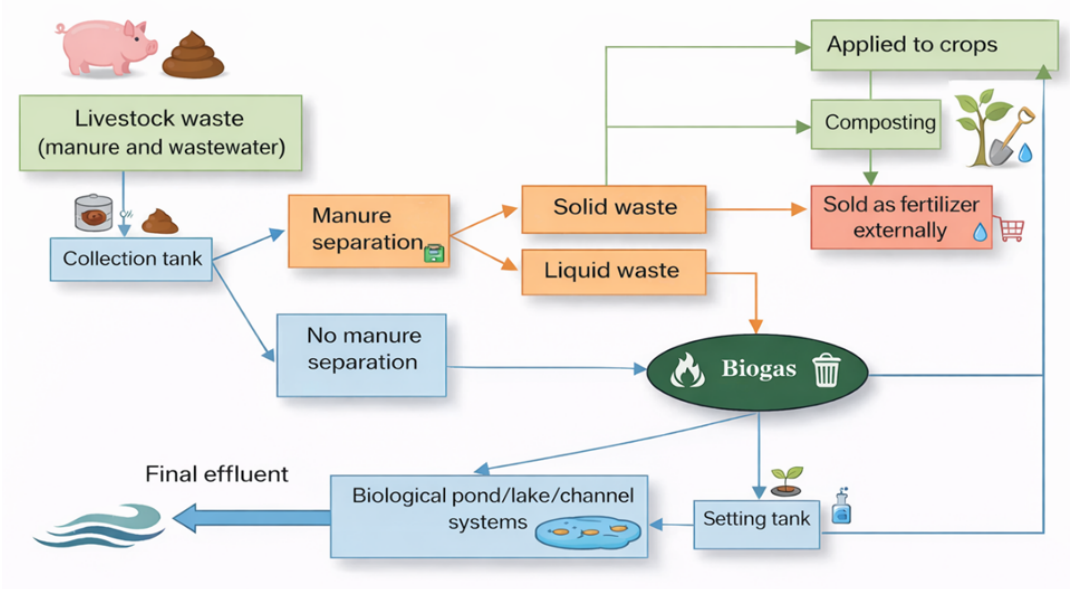

Figure 3. Wastewater treatment systems of contract farming in the study area

Table 6. Characteristics of waste treatment in contract farming (CF) and non-contract farming (NCF)

Waste-treatment and management practice	CFs (n = 70)		NCFs (n = 30)		Fisher's exact/Chi-square/t-test
	Number	Ratio (%)	Number	Ratio (%)	
Wastewater-treatment system					
Biogas	0	0.0	9	30.0	$p < 0.01$
Biogas → settling tank	27	38.6	3	10.0	
Biogas → biological pond	0	0.0	9	30.0	
Biogas → settling tank → biological pond	43	61.4	9	30.0	
Other waste-management practices					
Manure separation (yes)	17	24.3	29	96.7	0.000
Manure end uses (e.g., composting, direct application, fish feed, etc.)	34	48.6	14	46.7	0.000

more comprehensive and better organized because they were required to meet the technical requirements, environmental standards, and operating conditions demanded by the enterprise, while ensuring compliance with environmental protection laws governing livestock farming. In contrast, investment in and operation of waste treatment systems on NCFs largely depended on the conditions and awareness of individual farm owners, resulting in greater variation in waste treatment system design and the level of process control. This difference suggested that the CF model provided a mechanism for better compliance with waste management and disposal requirements, which could affect the treatment efficiency and environmental impact of pig farming operations.

3.1.3. Waste treatment efficiency

Although the farms had implemented relatively well-structured wastewater treatment systems, the current efficiency of wastewater treatment does not meet the requirements of QCVN 62:2025/BTNMT–National Technical Regulation on Livestock Wastewater. Accordingly, the concentration of pollutants in the effluent still exceeded permissible limits for many parameters. Table 7 shows that, except for the pH parameter, all other parameters in the effluents of both CF and NCF groups did not meet the regulatory requirements. This result indicated that although the farms have made considerable efforts to control the wastewater they generate, these sources remained unregulated.

Comparing the concentrations of pollutants in specific effluent streams, contract pig farms showed significantly lower concentrations compared to non-contract pig farms for most analyzed parameters (BOD_5, COD, TSS, TN, and TP). On the other hand, the rate of exceeding standards for pollutant parameters in the wastewater of the NCFs was slightly higher than that of the CFs. This showed that CFs' waste management systems were better organized than NCFs'.

3.2. Results of water quality analysis at contract pig farms

3.2.1. Surface water quality

The results of water quality monitoring in water bodies that received wastewater from CFs and NCFs are shown in Table 8.

For the surface water around CFs, Table 8 showed that the average BOD_5 content in the water reached 39 mg/L and 27 mg/L; COD reached 61 mg/L and 44 mg/L; NH_4^+ reached 0.54 mg/L and 0.89 mg/L; NO_2^- reached 0.13 mg/L and 0.14 mg/L; PO_4^{3-} reached 0.30 mg/L and 0.13 mg/L; coliform reached 4,110 MPN/100 mL and 2,270 MPN/100 mL, respectively, in the dry and rainy seasons. In general, pollutant concentrations in surface water were higher in the dry season than in the rainy season. A similar trend was also observed for surface water surrounding NCFs. The concentrations of BOD_5, COD, NH_4^+, NO_2^-, and PO_4^{3-} in surface water around CFs were higher than their concentrations in surface water around NCFs. Conversely, the average values of TSS and coliforms in surface water around CFs were lower. Overall, the difference in average concentrations of surface water pollutants between the two

Table 7. Effluent wastewater quality of CFs and NCFs

Parameters	Unit	CFs (*n* = 70)		NCFs (*n* = 30)		QCVN 62:2025/ BTNMT
		Mean	Exceeding rate (%)	Mean	Exceeding rate (%)	
pH	–	7.05	0.00	6.82	0.00	6.0–9.0
BOD_5	mg/L	161	91.43	1,069	96.67	≤60
COD	mg/L	450	92.86	1,870	96.67	≤150
TSS	mg/L	145	54.30	157	90.00	≤100
TN	mg/L	134	85.71	322	90.00	≤60
TP	mg/L	17.7	30.00	69.2	86.67	≤14
Coliform	MPN/100ml	161,423	91.43	44,093	96.67	≤5,000

Abbreviations: BOD_5: five-day biochemical oxygen demand; CF: Contract farming; COD: Chemical oxygen demand; NCF: Non-contract farming; TN: Total nitrogen; TP: Total phosphorus; TSS: Total suspended solids.

Table 8. Surface water quality around CFs and NCFs in the study area

Parameter	CFs (*n* = 30)		NCFs (*n* = 42)		QCVN08:2023/ BTNMT
	Dry season	Rainy season	Dry season	Rainy season	
pH	7.87	8.0	7.92	8.0	6.0–8.5
DO (mg/L)	6.35	6.14	5.97	6.18	≥4
BOD_5 (mg/L)	39	27	33	22	<6
COD (mg/L)	61	44	51	37	<15
NH_4^+ (mg/L)	0.54	0.89	0.70	0.64	<0.3
NO_2^- (mg/L)	0.13	0.14	0.05	0.10	<0.05
PO_4^{3-} (mg/L)	0.30	0.13	0.32	0.13	<0.2
TSS (mg/L)	38	47	39	51	<100
Coliform (MPN/100mL)	4,110	2,270	5,060	2,286	<5,000

Notes: *n* = number of sampled farms; QCVN 08:2023–Column B: Vietnam National Technical Regulation on Surface Water Quality–Column B (water quality ensuring aquatic life support).
Abbreviations: BOD_5: five-day biochemical oxygen demand; CF: Contract farming; COD: Chemical oxygen demand; DO: Dissolved oxygen; NCF: Non-contract farming; NH_4^+: Ammonia; NO_2^-: Nitrite ion; PO_4^{3-}: Phosphate ion; TSS: Total suspended solids.

CF and NCF areas was not significant in either the rainy or dry seasons.

3.2.2. Groundwater quality

The results of groundwater quality analysis at 70 contract pig farms are shown in Table 9. The average concentration of NH_4^+ was 0.31 mg/L in the dry season and 0.29 mg/L in the rainy season. On the other hand, the corresponding concentrations of NO_3^- were 0.29 mg/L and 0.21 mg/L. The pH and EC values were 6.54 and 6.62, respectively; 264 µS/cm and 188 µS/cm in the dry and rainy seasons. Pollutant concentrations were higher in the dry season than in the rainy season, but the differences were not statistically significant. Meanwhile, in the control group (NCFs), NH_4^+ concentrations reached 0.58 mg/L and 0.55 mg/L during the dry and rainy seasons, respectively. These values were higher than their concentrations in groundwater at the CFs. Conversely, the NO_3^- concentration in groundwater at NCFs was significantly lower than at CFs, with an average value of 0.12 mg/l for both the rainy and dry

seasons. The concentrations of NH_4^+ and NO_3^- in the groundwater in both CF and NCF areas were low and met the requirements of QCVN09:2023/BTNMT–Vietnam National technical standard on groundwater quality (Table 9). In addition, the EC values in the groundwater of the CFs were 264 µS/cm and 188 µS/cm during the dry and rainy seasons, respectively. These values were significantly higher than their corresponding values in groundwater in the NCF areas (136 µS/cm and 120 µS/cm in the dry and wet seasons, respectively). Although EC is not a pollution parameter, its value is generally proportional to the concentration of dissolved ions in water. Therefore, EC can be an indicator for assessing the risk of pollutants seeping from the land surface into groundwater.[33,34]

4. Discussions

4.1. Waste sources and treatment efficiency

Waste (solid and liquid) from pig farms has long been recognized as a major source of environmental pollution in agricultural and rural areas.[8,35] Characterized by its high content of easily biodegradable organic compounds of nitrogen and phosphorus, many harmful microorganisms, and high levels of suspended solids, waste from pig farming poses a high risk of environmental contamination, especially to surface and groundwater in the areas surrounding the farms.[15,16] Survey results from 70 contract pig farms in the suburban areas of Hanoi showed that most farms used biogas technology combined with other methods, such as manure separation, composting, and using biological ponds/lake systems to treat waste. These waste management practices significantly reduced pollutant concentrations in wastewater. However, most contract pig farms in the study area did not comply with the requirements of QCVN 62:2025/BTNMT. Consequently, water bodies receiving wastewater from these farms remain at risk of pollution and degradation.[36]

According to the generation coefficients of the Vietnamese Ministry of Agriculture and Environment, on average, one pig produces 0.8 kg of manure per day and about 50 liters of wastewater per day. The average herd size was 2,642 pigs/farm for CFs, compared with 821 pigs/farm for NCFs (Table 5). The estimated volume of waste generated is approximately 5.28 tons of manure/day and 132.10 m^3 of wastewater/day at CFs, and approximately 1.64 tons of manure/day and 41.05 m^3 of wastewater/day at NCFs. This shows that environmental pressure from waste sources at CFs is significantly greater than at NCFs. Although the waste treatment efficiency from analyses at CFs was generally better, with lower effluent pollutant concentrations, it was still insufficient to offset the increased environmental pressure caused by the large volume of waste generated. Furthermore, the actual wastewater output from CFs did not meet the requirements of QCVN 62:20205/BTNMT. This is considered one of the main causes of serious environmental pollution in the water bodies surrounding pig farms. In addition, surface water pollution poses a risk of groundwater contamination through leaching of water from surface water into groundwater. In addition, the leaching of pollutants from above into groundwater, especially nitrogen compounds, increases the risk of groundwater contamination.[10,14,37]

4.2. Impact of contract pig farms on surface water quality

The results comparing the average concentrations of surface water quality parameters with QCVN08:2023/BTNMT showed that in the CFs area, five out of nine parameters (BOD_5, COD, NH_4^+, NO_2^-, and PO_4^{3-}) did not meet the standards during the dry season, and four out of nine parameters (BOD_5, COD, NH_4^+, and NO_2^-) did not meet the standards during the rainy season. This number tends to be higher in NCF areas, with six out of nine

Table 9. Results of groundwater quality analysis of CFs and NCFs in the study area

Parameters	CFs (n = 70)		NCFs (n = 30)		QCVN 09:2023/BTNMT
	Dry season	Rainy season	Dry season	Rainy season	
pH	6.54	6.62	6.02	6.47	5.8–8.5
EC (µS/cm)	264	188	136	130	–
NH_4^+ (mg/L)	0.31	0.29	0.58	0.55	1
NO_3^- (mg/L)	0.29	0.21	0.12	0.12	15

Notes: n = number of sampled farms; QCVN 09:2023–Vietnam National Technical Regulation on Ground Water Quality.
Abbreviations: CF: Contract farming; EC: Electrical conductivity; NCF: Non-contract farming; NH_4^+: Ammonia; NO_3^-: Nitrate.

parameters failing to meet standards during the dry season (BOD_5, COD, NH_4^+, NO_2^-, PO_4^{3-}, and coliform) and four out of nine parameters failing to meet standards during the rainy season (BOD_5, COD, NH_4^+, and NO_2^-). In particular, the level of pollution in the CF areas was slightly less severe than in the NCF areas (Table 8).

The calculated WQI results for water bodies surrounding CFs and NCFs are shown in Table 10. These results clearly showed the differences between the two farming groups and exhibited seasonal variations. For the CFs, the average WQI values reached 63.97 and 67.85 points for the dry and rainy seasons, respectively, both indicating average quality. Meanwhile, in the area surrounding the NCFs, the average WQI value reached 40.92 points (poor quality) during the dry season and 67.13 points (average quality) during the rainy season. Thus, surface water quality in CF areas was slightly better than in NCF areas. Specifically, the NCFs had a significantly higher percentage of surface water classified as severely polluted, at 53.33% in the dry season and 20.00% in the rainy season, while the CFs accounted for only 3.33% and 10.00% in the dry and rainy seasons, respectively (Table 10).

The results of comparing surface water quality with QCVN 08:2023/BTNMT combined with the WQI index assessment showed that, although CFs had better waste management and treatment systems, resulting in lower concentrations of pollutants in effluent and more stable overall water quality (as shown in the WQI calculation results), the large scale and high stocking density of livestock led to a larger volume of waste generated, resulting in high levels of local surface water pollution (as shown in the comparison with QCVN 08:2023/BTNMT). CFs have invested more, prioritized, and effectively implemented waste management practices than NCFs, resulting in lower environmental impacts than the NCFs.[17] However, this level of improvement is still insufficient to meet pollution control regulations, and therefore continues to negatively impact surface water quality. The main explanation for this is that CFs typically operate on a much larger scale in livestock production than NCFs (3.2 times higher). This means that the volume of waste generated from CFs will be 3.2 times higher than that from NCFs. Although the treatment efficiency was higher than that of the NCFs, the pollutant concentration in the wastewater from the CFs still did not meet the permissible limits set by QCVN 62:2025/BTNMT. As a result, CFs continue to negatively affect the surface water quality of surrounding wastewater-receiving bodies. This shows that, alongside promoting the development of livestock farming according to the CF model, the Vietnamese government needs to pay special attention to controlling and addressing waste generated from these farms. Only in this way can the problem of surface water pollution around concentrated pig farming areas be completely resolved.

Table 10. Results of water quality index (WQI) calculations in water bodies receiving wastewater from contract farming (CF) and non-contract farming (NCF)

WQI score	Water quality	CFs (n = 40)				NCFs (n = 42)			
		Rainy season		Dry season		Rainy season		Dry season	
		Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)
91–100	Very good	0	0.00	0	0.00	1	3.33	6	20.00
76–90	Good	6	20.00	14	46.67	10	33.33	17	56.67
51–75	Moderate	17	56.67	11	36.67	9	30.00	9	30.00
26–50	Poor	3	10.00	1	3.33	3	10.00	2	6.67
10–25	Very poor	1	3.33	0	0.00	1	3.33	0	0.00
<10	Heavily polluted	1	3.33	3	10.00	16	53.33	6	20.00
Mean of WQI		63.97 ± 17.02		67.85 ± 22.89		40.92 ± 34.88		67.13 ± 28.08	

4.3. Impact of contract pig farms on groundwater quality

A comparison of groundwater quality at contracted and non-contracted pig farms with QCVN 09:2023/BTNMT showed that the average values of pH, NH_4^+, and NO_3^- parameters in both areas were within the permissible limits. This indicated that groundwater quality in the study area remained good and not polluted.

The average concentration of NO_3^- in groundwater in both CF and NCF areas during the dry and rainy seasons was still much lower than the World Health Organization (WHO's) recommended threshold of 10 mg/L for drinking water quality. However, the WHO recommends that the concentration of NH_4^+ in groundwater should be < 0.5 mg/L to limit corrosion and damage to water pipes. In this study, the NH_4^+ values in groundwater of the CFs were lower than 0.5 mg/L, but for groundwater in the NCFs, the average NH_4^+ concentration exceeded the recommended threshold of 0.5 mg/L. On the other hand, although the groundwater in the CFs was not yet contaminated by nitrogen compounds, the average EC values measured were significantly higher than in the NCFs during both the rainy and dry seasons. This is a potential indicator of high groundwater contamination risk, as EC values are generally proportional to the concentration of ions in groundwater. In addition, EC is directly related to the risk of pollutants seeping from the land surface into groundwater.[33,34] Therefore, although the groundwater in the pig farming area is not yet polluted, further monitoring and assessment are still needed in the future.

The calculated CPI for groundwater in CF and NCF areas is shown in Table 11. The results indicated that groundwater quality at these two farm groups was mostly in the "clean" and "sub clean" categories during both the dry and rainy seasons. In NCF areas, only slightly polluted levels were recorded during the dry season, at a rate of 36.67% (occurring at 11 farms) (Table 11). Thus, the CPI assessment results showed that only a small percentage of NCFs exhibited slight pollution during the dry season, primarily associated with NH_4^+ content. CFs have not yet had a negative impact on groundwater quality.

Groundwater pollution in pig-farming areas, particularly by inorganic nitrogen, has been documented in numerous studies both domestically and internationally.[10,16] This is because nitrogen compounds are highly soluble in water and can seep through the soil and enter the aquifer, thereby causing a decline in groundwater quality.[10,35,36] However, the results of groundwater quality analysis at 100 surveyed farms, combined with the results of the CPI assessment, showed that groundwater quality in the study area was generally good. Only a small percentage, approximately 36.67%, of the uncontracted pig farms were classified as having slightly polluted groundwater quality according to the CPI index during the dry season. This indicates that the impact of uncontracted pig farming on groundwater quality is beginning to emerge, especially given the low groundwater infiltration rates during the dry season. Meanwhile, the negative impacts of CFs on groundwater quality had not been documented in the study area. This is a very positive finding compared with previous research results. Groundwater in Vietnam's concentrated pig farming areas was polluted by inorganic nitrogen, specifically NH_4^+ concentrations frequently exceeding

Table 11. Calculation results of the comprehensive pollution index (CPI) in groundwater of contract farming and non-contract farming in the study area

CPI	Pollution level	CFs				NCFs			
		Rainy season		Dry season		Rainy season		Dry season	
		Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)
<0.2	Clean	51	72.86	59	84.29	15	50.00	30	100
0.2–0.4	Sub clean	19	27.14	11	15.71	4	13.33	0	0
0.4–1.0	Slightly polluted	0	0	0	0	11	36.67	0	0
1.0–2.0	Medium polluted	0	0	0	0	0	0	0	0
≥2.0	Heavily polluted	0	0	0	0	0	0	0	0
Mean of CPI (mean ± SD)		0.162 ± 0.070		0.152 ± 0.071		0.296 ± 0.246		0.012 ± 0.021	

permissible levels.[14-16]

4.3. Proposing solutions to minimize the impact of pig farms on water quality

Research results have shown that the impacts of the CFs on surface water environments were significantly lower than those of the NCFs. This shows that promoting the development of the CFs is the right direction and should be continued and implemented in the future. However, the research results also showed that although the impacts of CFs on the aquatic environment were lower than those of the NCFs, they still negatively affected surface water quality.[37,38] The reason is that the wastewater generated from CF farms does not meet QCVN62/BTNMT–the Vietnam National Technical Standard on Livestock Wastewater. Therefore, alongside promoting the development of pig farming in accordance with the CFs, the Vietnamese government needs to more strictly control the waste generated by pig farms and ensure that 100% of it is controlled and treated to meet requirements before being discharged into the environment. Furthermore, the Vietnamese government needs to encourage pig farmers to shift their mindset in managing pig farming waste from a passive approach (treatment and disposal) to a proactive approach (reduction and reuse). In this context, developing circular and closed-loop waste management models for pig farming is a key solution. This solution can minimize environmental impacts (reducing waste generation) while also generating additional income for pig farms, helping them achieve high ecological efficiency.[39,40]

In addition, the Vietnamese government needs to continue monitoring and supervising groundwater quality in areas with concentrated pig farming. Although groundwater in these areas is not yet polluted, the risk of pollutants leaching from the surface into groundwater remains high, posing a significant risk of future pollution.[33,34]

5. Conclusion

The trend of developing CFs is gaining momentum in Vietnam due to their superior production organization and integrated waste management systems. This study showed that CFs were capable of raising pigs at higher densities (3.2 times higher) and had better control and utilization of waste. However, the wastewater treatment systems at CF farms in the study area did not meet the requirements of QCVN62:2025–the Vietnam National Technical Standard on Livestock Wastewater, with six out of seven effluent quality indicators failing to meet the requirements.

The activities of CFs have adversely affected surface water quality in surrounding receiving water bodies, with average concentrations of COD, BOD_5, NH_4^+, NO_2^-, and PO_4^{3-} frequently exceeding the permissible limits set by QCVN08:2023/BTNMT, the Vietnam National Technical Standard on surface water quality. In addition, the WQI reached only 63.97 points and 67.85 points in the dry and rainy seasons, respectively, both indicating average water quality. Conversely, groundwater quality in the CFs area remained good, with average concentrations of NH_4^+ and NO_3^- consistently below the permissible limits of QCVN09:2023/BTNMT–National Technical Standard on Groundwater Quality. On the other hand, the average CPI for groundwater was 0.162 points and 0.152 points in the dry and rainy seasons, respectively, both of which were classified as clean. Thus, there has been no adverse impact on groundwater quality from CFs.

Comparisons of pollution levels and surface and groundwater quality in CFs showed more favorable outcomes than in NCFs. This shows that developing farms based on the CF model is the right direction to minimize negative impacts on the aquatic environment. However, to thoroughly address water pollution in concentrated pig-farming areas, the Vietnamese government needs to improve wastewater treatment systems at these farms and strictly enforce regulations on wastewater discharge.

This is a preliminary study aimed at identifying the impact of contract pig farms on the aquatic environment compared to other farms. It is still in the exploratory and evaluative stages and has not yet applied advanced techniques and models; therefore, the research results are still limited. Many in-depth aspects of the CFs, such as ecological efficiency, greenhouse gas emissions, and carbon footprint, need further investigation. Based on this, appropriate recommendations are made to government agencies to improve wastewater management practices and promote sustainable development of contract pig farms.

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Conflict of interest

The authors declare they have no competing interests.

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Availability of data

Data are available from the corresponding author upon reasonable request.

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