

Assessing The Impact Of Contract Pig-Farms On The Water Environment In Vietnam

Bui Phung Khanh Hoa¹, Le Thi Thu Huong², Tran Trong Phuong³, Nguyen Hai Nui⁴, Le Xuan Sinh⁵, Tran Thi Thanh Huyen⁶, Cao Truong Son^{7*}

¹Faculty of Natural Resources and Environment, Vietnam National University of Agriculture, Hanoi, Vietnam, Email: bpkhoa.tnmt@vnua.edu.vn

²Faculty of Accounting and Business Administration, Vietnam National University of Agriculture, Hanoi, Vietnam, Email: ltthuong@vnua.edu.vn

³Faculty of Natural resources and Environment, Vietnam National University of Agriculture, Hanoi, Vietnam. Email: tranphuongnn@gmail.com, <https://orcid.org/0000-0002-0592-3037>

⁴VNU University of Economics and Business, Hanoi, Vietnam. Email: hainui@gmail.com, <https://orcid.org/0000-0002-7719-3088>

⁵Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi, Vietnam. Email: sinhlx@gmail.com, <https://orcid.org/0000-0002-1043-5054>

⁶Faculty of Accounting and Business Administration, Vietnam National University of Agriculture, Hanoi, Vietnam, Email: huyenqt@gmail.com

^{7*}Corresponding Author: Leader of The Elite Research Group: Environmental Management and Sustainable Development, Vietnam National University of Agriculture, Hanoi, Vietnam. Email: caotruongson.hua@gmail.com, <https://orcid.org/0000-0002-3115-5123>

Abstract

Pig farming is an important economic sector of agriculturally developed countries in the world, including Vietnam. However, this activity is also causing major impacts on the water quality around concentrated pig farming areas. This study was conducted to assess the impact of contract pig-farms on the aquatic environment in Vietnam. 100 pig farms (including 70 contract pig-farms and 30 non-contract pig-farms as controls) in the suburban area of Hanoi city were selected for the study. We conducted a questionnaire survey, collected samples of waste sources, surface water, and groundwater around the contracted and non-contracted pig-farms areas to compare with environmental standards, and calculated the Comprehensive Pollution Index (CPI). The results show that contracted pig farms are seriously affecting surface water quality. In contrast, the impact of contract pig-farms on groundwater quality is unclear. Compared with non-contract pig-farms, the impact on surface water environment of contract pig-farms is significantly higher. The main reason is the difference in pig farming scale (average number of pigs raised is 3.14 times higher) and the waste treatment system does not meet the requirements. To solve this situation, the conversion of traditional pig-farm models to circular pig-farm models, reducing emissions, needs to be implemented soon in the near future.

Keywords: Contract pig farming, environmental impact, groundwater, pollution, 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 (Turner et al, 2024) [1]. 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 (FAO, 2006)[2]. In the livestock sector, FAO (2006) 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 documented the impact of livestock farming on aquatic environments. Results show that untreated livestock wastewater is a major source of organic, nutrient, and microbial pollution to both surface and groundwater. In China - the world's largest livestock producer the concentrations of COD, T-N, and T-P in piggery wastewater can reach 1,000 to 15,000, 100 to 2,100, and 20 to 350 mg/L, respectively (Zhang et al, 2021) [3]. Livestock wastewater contributes an estimated 41.9%, 21.7%, and 37.9% of the country's national COD, T-N, and T-P discharges, making it the primary source of water pollution (Sun et al., 2021) [4]. Similarly, Li et al. (2022) [5] examined multiple river basins globally and concluded that livestock, especially pig farming, is a dominant contributor of organic matter, nitrogen, phosphorus, and microorganisms to water bodies, thereby increasing the risk of eutrophication and surface water degradation in areas of intensive farming. Groundwater is also significantly affected. Mohammadi et al. (2023) [6], studying the Çıldır Lake basin in Turkey, found that during the dry season, groundwater contamination by total coliform increased from 56% to 92% and by fecal coliform from 26% to 85%, while nitrate concentrations rose from 6.4 to 7.1 mg/L. This indicates infiltration of livestock waste into shallow aquifers, heightening microbial and nutrient risks. In Mexico, Pedrozo-Acuña et al. (2025) [7] reported that rapid pig farm expansion on karst terrain in the Yucatán Peninsula has exacerbated groundwater pollution, with nitrate concentrations in wells and cenotes exceeding drinking-water standards, posing a serious threat to local communities. Collectively, this evidence underscores the substantial pressure that livestock farming places on water resources and highlights the need for context-specific research in Vietnam, where pig production plays a central role.

In Vietnam, several studies have demonstrated the adverse impacts of pig farming on surface and groundwater. Tra et al. (2010) [8] found that water resources in Lai Vu commune (Hai Duong) were heavily polluted with $\text{NH}_4^+\text{-N}$, with contamination levels directly proportional to herd size. Tra et al. (2013, 2016) [9, 10] further confirmed that COD, BOD, $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$, TSS, and Coliform concentrations all exceeded QCVN standards. Their 2016 study also showed that although VAC systems (garden-pond-livestock) exerted less pressure on water quality than VC systems (pond-livestock), both still exceeded permissible thresholds. More recent work on waste management (Huong et al., 2021) [11]. indicated that larger farms perform better than smaller ones, yet both contribute to COD, T-N, and T-P loads.

Contract farming (CF) is a common trend in the agricultural sector in most countries around the world. Costales et al. (2006) [12] and Ogishi et al. (2003) [13] describe CF as a structured arrangement where agribusiness companies supply farmers with inputs like feed and breeding stock, while farmers, in return, deliver the raised animals to be processed and marketed to end consumers. It allow integrators to play a key role in the agricultural sector. Through farming contracts, the integrators can introduce modern production techniques and connect farmers to markets, helping them obtain inputs at lower costs or sell outputs at higher prices. As a result, net income per unit of production has increased in several Asian countries, including India, Thailand, the Philippines, and Vietnam (Costales & Catelo, 2008) [14]. Moreover, CF is considered an institutional innovation that provides young people in East African countries such as Burundi, Kenya, Rwanda, and Uganda with opportunities to overcome financial and knowledge barriers and generate income within rural areas (Menezes et al., 2018) [15]. While integrators make significant contributions, they may also contribute to environmental pollution if environmental considerations are not integrated into their management practices. Delgado et al. (2008) [16] and Ogishi et al. (2003)[13] noted that in the United States and Brazil, responsibility for pollution from animal waste rests solely with contract farmers who raise the livestock, while integrators are exempt from liability. However, because contract farmers often lack sufficient financial resources and government enforcement is weak, even when farmers fail to meet environmental regulations, they are rarely penalized. In effect, contract farming serves as a mechanism that shifts the burden of environmental liability from agribusiness firms to the farmers themselves.

Currently, CF is rapidly expanding in Vietnam, particularly among medium- and large-scale farms linked to foreign direct investment (FDI) enterprises such as CP, Japfa, CJ, and Dabaco. These farms benefit from guaranteed markets, technical and veterinary support, and investment in more advanced waste treatment systems. By contrast, noncontract farming (NCF) still accounts for the majority of small-scale pig farms, which face capital and land constraints and therefore present higher risks of water pollution (Huong et al., 2020) [17]. Huong et al. (2020) [17] compared CF and NCF and found that CF farms exhibited lower pollution

levels due to larger areas and more advanced treatment systems. Overall, domestic studies provide strong evidence of the environmental impacts of pig farming, while also showing variations by production model (VAC vs. VC), farm scale (large vs. small), and management type (CF vs. NCF). However, no study to date has systematically assessed differences between CF and NCF in their impacts on surface and groundwater quality. This raises an important research question: how does contract farming influence the aquatic environment, and to what extent does its impact differ from non-contract farming? This study aims to address this knowledge gap and provide a scientific basis for environmental management and policy planning to support sustainable pig production while minimizing negative impacts on Vietnam's water resources.

2. Study Area

This study was conducted in the suburban areas of Hanoi, the capital of Vietnam. Hanoi is located in the northwest of the Red River Delta, covering 3,359.8 km² with a population of 8.7 million in 2024. The city has an extensive agricultural land area of 196,600 hectares and a rural population of approximately 4.4 million people, accounting for 50.9% of the total population (General Statistics Office, 2025) [18].

The topography of Hanoi slopes gradually from north to south and from west to east, with an average elevation of 5–20 meters above sea level. The dominant landscape is flat terrain (three-quarters of the area), while hilly areas are concentrated in the northern and western suburbs, with several low hills scattered within the inner city. Hanoi's climate is characterized by a tropical monsoon regime with two distinct seasons: the rainy season (April–October) and the dry season (November–March). The average annual temperature is 23.6 °C (above 27 °C in summer and around 22 °C in winter), with average annual rainfall ranging from 1,500 to 1,900 mm. These natural conditions are favorable for livestock production, particularly pig farming in suburban districts.

As a result, Hanoi consistently ranks among the leading provinces in Vietnam in pig herd size and live pig output, ranking third nationally with 1.28 million pigs and 261.7 thousand tons, respectively. The city also has the highest number of pig farms nationwide, with 2,313 farms, including 232 medium- and large-scale farms operating under contract farming arrangements. Contract farms account for approximately 51% of Hanoi's total pig population (General Statistics Office, 2025) [18].

The study focused on suburban districts where pig production is concentrated, including 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). The primary research subjects were contract pig farms, defined as farms operated by local households under agreements with large livestock companies or corporations. A total of 100 pig farms were surveyed, comprising 70 contract farms (study group) and 30 non-contract farms (comparison group).

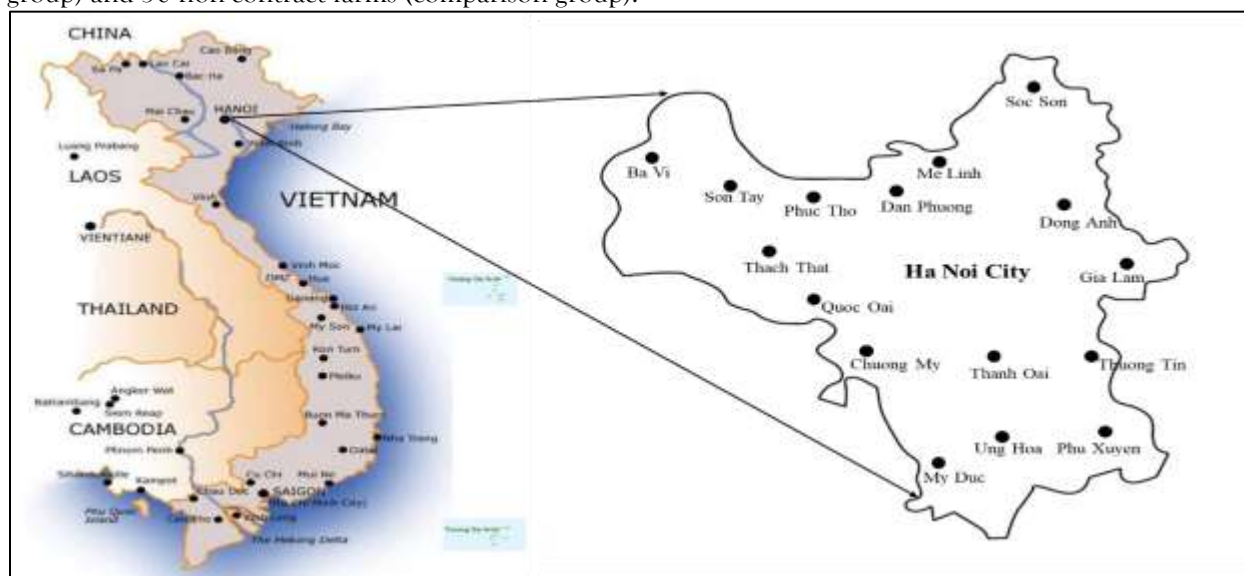


Figure 1. Location of study areas on the map of Vietnam

3. Study Methods

3.1. Water sampling method

Wastewater samples: To evaluate the wastewater treatment efficiency of each farm, one effluent sample was collected from the outlet of the treatment system. In total, 100 farms were sampled, including 70 contract farms and 30 non-contract farms. Sampling was conducted between June and August 2024. The analyzed parameters included pH, BOD₅, COD, TSS, TN, TP, and Coliform.

Groundwater samples: A total of 100 groundwater samples were collected from active wells at livestock farms, with well depths ranging from 10 to 20 meters. Of these, 70 samples were obtained from contract farms and 30 from non-contract farms. Sampling was carried out in two periods: the rainy season (June to August 2024) and the dry season (December 2024 to January 2025). Parameters analyzed included pH, electrical conductivity (EC), ammonium (NH₄⁺-N), and nitrate (NO₃⁻).

Surface water samples: Surface water quality data were obtained from monitoring conducted by the Hanoi Department of Agriculture and Environment in 2024, covering two monitoring periods: the dry season (March to April 2024) and the rainy season (July to August 2024). A total of 72 monitoring sites were included, comprising 30 locations in ponds, lakes, rivers, and streams influenced by wastewater from contract farms, and 42 locations in areas affected by wastewater from non-contract farms. Parameters analyzed included pH, temperature, DO, BOD₅, COD, NH₄⁺-N, NO₂⁻-N, PO₄³⁻-P, TSS, and Coliform.

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

No.	Environmental component	With contract	No contract	Analytical parameters
1	Wastewater	70	30	
1.1	Effluent	70	30	pH, BOD ₅ , COD, TSS, TN, TP, and Coliform
2	Groundwater	140	60	
2.1	Rainy season (June–July 2024)	70	30	pH, electrical conductivity (EC), ammonium (NH ₄ ⁺), nitrate (NO ₃ ⁻).
2.2	Dry season (December 2024 – January 2025)	70	30	pH, electrical conductivity (EC), ammonium (NH ₄ ⁺), nitrate (NO ₃ ⁻).
3	Surface water*	60	84	
3.1	Rainy season	30	42	pH, temperature, DO, BOD ₅ , COD, NH ₄ ⁺ , NO ₂ ⁻ , PO ₄ ³⁻ , TSS, and Coliform
3.2	Dry season	30	42	pH, temperature, DO, BOD ₅ , COD, NH ₄ ⁺ , NO ₂ ⁻ , PO ₄ ³⁻ , TSS, and Coliform

Note: (*) Surface water data were inherited from monitoring results of Agriculture and Environment, Hanoi City

3.2. Analysis Method

Parameters such as pH, EC, temperature, and DO in wastewater and groundwater samples were measured on-site using a portable multi-parameter meter. The remaining parameters were analyzed at the ISO-certified laboratory of the Vietnam National University of Agriculture. Specifically, ammonium and nitrate concentrations were determined using colorimetric methods with the Nesslerization (American Public Health Association, 1992) [19] and Catado techniques (Catado et al., 1975) [20], respectively. BOD₅ was measured by dilution and incubation at 20 °C (ISO, 1989) [21], while COD was determined by the potassium dichromate titration method (American Public Health Association, 1992) [19]. Suspended solids and coliform counts were analyzed using gravimetric (ISO, 1997) [22] and colony-counting methods (ISO, 1990)

[23], respectively. All analytical procedures complied with the current regulations of the Vietnamese Ministry of Agriculture and Environment.

3.3. Impact assessment method

* Comparison with national standards

To evaluate the impact of pig farms on the aquatic environment, the results of wastewater, surface water, and groundwater analyses were compared with the current Vietnamese environmental standards, as follows:

- Wastewater samples were compared with QCVN 62-MT:2016/BTNMT – National Technical Regulation on Livestock Wastewater.

- Surface water samples were compared with QCVN 08:2023/BTNMT – National Technical Regulation on Surface Water Quality.

- Groundwater samples were compared with QCVN 09:2023/BTNMT – National Technical Regulation on Groundwater Quality.

* Comprehensive Pollution Index (CPI):

CPI is used to assess the pollution level of a water body based on water monitoring parameters (Matta et al., 2017) [24]. The formula for calculating CPI is as follows:

$$(1) \quad (2) \quad \frac{PI}{CPI} = \frac{C_i}{S_i} = \frac{1}{n} \sum_{i=1}^n PI_i$$

Where: n - number of water monitoring parameters; PI_i - Pollution index of the i th parameter is calculated by the formula 1. In Equation 1, C_i is the concentration of parameter i in the water body; S_i is the allowable limit of parameter i specified in water environmental regulations. CPI is rated on a scale, which is described in **Table 2**.

Table 2. Rating scale for CPI

No	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	Moderately polluted
5	> 2.01	Heavily polluted

In this study, the Comprehensive Pollution Index (CPI) for surface water was calculated using the concentrations of seven parameters: BOD₅, COD, NH₄⁺, NO₂⁻, PO₄³⁻, TSS, and Coliform. For groundwater, the CPI was calculated based on two parameters: NH₄⁺ and NO₃⁻.

3.4. Data processing

Descriptive statistical analysis and T-tests were performed using Microsoft Excel to compare livestock farming characteristics and water quality parameters between contract and non-contract farming systems. Statistical significance was evaluated at the 1%, 5%, and 10% levels.

4. RESULTS

4.1. Livestock farming conditions in the study area

* Livestock characteristics

Survey results from 100 pig farms in the study area showed clear differences between contract and non-contract farms (**Table 3**). The average farm area was 11,975 m² (approximately 1.2 ha) for contract farms and 6,175 m² (approximately 0.6 ha) for non-contract farms. The average barn area exceeded 4,000 m² (43.47% of the total area) on contract farms, compared with 1,300 m² (34.64%) on non-contract farms. Contract farms also operated at a larger scale, with an average of 2,642 pigs per farm compared with 821 pigs on non-contract farms. Consequently, pig density was higher on contract farms both per unit farm area (0.512 vs. 0.225 pigs/m²) and per unit pen area (0.703 vs. 0.657 pigs/m²). Although the environmental treatment area on contract farms (5,814 m², accounting for 51.29% of the total farm area) was larger than that on non-contract

farms (3,208 m², 40.34%), the ratio of treatment area per livestock unit was significantly lower on contract farms (2.701 m²/animal) compared with non-contract farms (6.152 m²/animal).

Table 3. Basic characteristics of contract and non-contract pig farms in the study area.

Indicators	Contract farms	Non-contract farms	Difference (between contract and non-contract)	
	(X± SD)	(X± SD)	Difference	P-value
Farm area (m ²)	11,975±8118	6,175±5,419	80***	7.24815E-05
Pig pen area (m ²)	4,009 ± 2,658	1,323 ± 1,074	98***	1.26411E-10
Environmental treatment area (m ²)	5,814 ± 4,902	3,208 ± 4,384	61***	0.010884223
Ratio of livestock pen area to total area (%)	43.47 ± 28.52	34.64 ± 29.34	54	0.169955674
Ratio of environmental treatment area to total area (%)	51.29 ± 24.16	40.34 ± 29.34	47	0.078436534
Total number of pigs raised (head)	2,642 ± 1,652	821 ± 758	97***	2.35876E-11
Pig density in the farm (pigs/m ²)	0.513 ± 0.242	0.225 ± 0.225	59***	3.52532E-07
Average number of pigs per pen area (pigs/m ²)	0.703 ± 0.249	0.657 ± 0.331	80***	8.3065E-07
Environmental treatment area per animal (m ² /animal)	2.701 ± 2.793	6.152 ± 10.458	30	0.030690085

Note: (*), (**), (***) indicate statistical significance at the 10%, 5%, and 1% levels, respectively. X ± SD = Mean ± standard deviation

Table 3 also indicates that most basic characteristics—including farm area, pen area, environmental treatment area, number of pigs raised, pig density per farm area, average pig density per pen area, and environmental treatment area per pig—showed statistically significant differences between contract and non-contract farms at the 1% and 5% levels. Only two indicators, namely the ratio of pen area to total farm area and the ratio of environmental treatment area to total farm area, showed no statistically significant differences between the two farm types.

*** Waste management measures**

Survey results revealed that the predominant waste treatment technology on pig farms involves the use of biogas digesters in combination with other treatment methods, as illustrated in **Figure 2**.

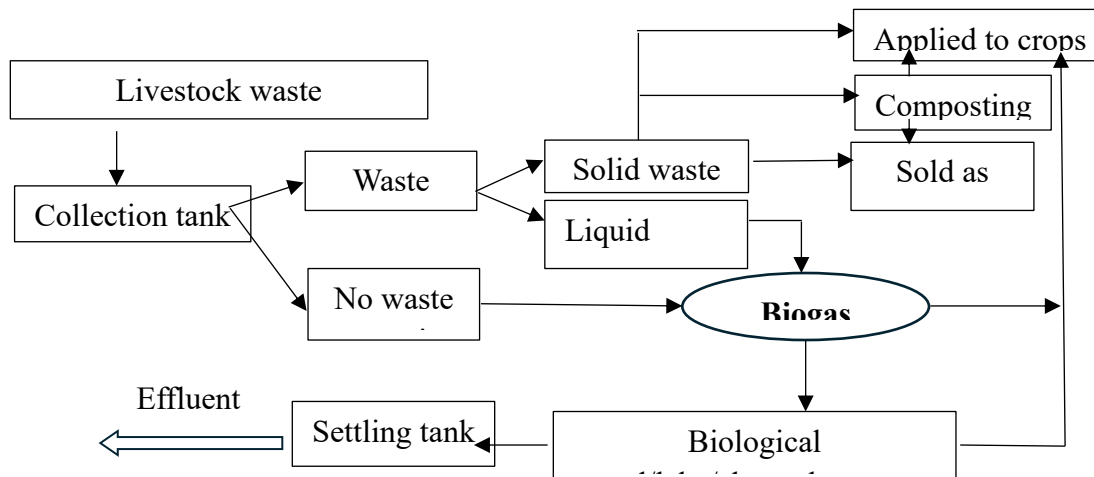


Figure 2: Typical waste treatment system of pig farms in the study area

Figure 2 illustrates the waste treatment system commonly applied on pig farms. After collection, pig manure and wastewater are either separated into solid and liquid fractions using settling tanks or manure presses, or directed directly into biogas digesters without separation. Solid waste is generally composted and applied as fertilizer to crops, with a portion sold or used directly without composting. Liquid waste is routed to biogas digesters for biogas production. On farms without waste separation, the entire manure-wastewater mixture is fed directly into biogas tanks. The generated biogas is used for heating or electricity to meet farm needs. Effluent from biogas digesters is discharged into biological ponds, lakes, or ditches for further treatment, followed by settling tanks before final discharge to the environment. A small portion of effluent is reused for crop irrigation.

There were no fundamental differences in waste treatment technologies between contract and non-contract farms. However, contract farms generally demonstrated higher investment, stricter operational procedures, and better facility maintenance, reflecting compliance with contract requirements. In contrast, non-contract farms often lacked effective environmental management, with systems built primarily to satisfy regulatory inspections rather than to ensure consistent treatment efficiency. This discrepancy directly influenced the effectiveness of waste treatment across farm types.

* Wastewater treatment efficiency

The results of wastewater analysis from 100 pig farms in the study area are presented in Table 4.

Table 4. Pollutant characteristics in the effluent of pig farms

Parameter	Contract Pig Farm (n = 70)			Non-Contract Pig Farm (n = 30)			QCVN62:2025 Column B
	Min - Max	X ± SD	Rate of exceeding QCVN62:2025	Min - Max	X ± SD	Rate of exceeding QCVN62:2025	
pH	5.16 - 8.04	7.05 ± 0.56	0.00	5.44 - 7.88	6.82 ± 0.49	0.00	6.0 - 9.0
BOD ₅	43 - 2292	161 ± 272	91.43	33 - 5531	1069 ± 1131	96.67	60
COD	12 - 7,336	450 ± 885	92.86	65 - 9032	1870 ± 1793	96.67	150
TSS	8 - 625	145 ± 127	54.30	16 - 500	157 ± 95.86	90.00	100
TN	51 - 293	133 ± 50.26	85.71	5.6 - 2536.8	322.3 ± 484.16	90.00	60
TP	1.2 - 112.4	17.67 ± 20.96	30.00	4.5 - 511	69.2 ± 93.1	86.67	14
Coliform	2800 - 920,000	161,423 ± 252,497	91.43	4,800 - 200,000	44,093 ± 60,221	96.67	5000

Table 4 shows that despite substantial efforts in waste management, both contract and non-contract pig farms failed to meet the requirements of QCVN 62:2025 - National Technical Regulation on Livestock Wastewater. Except for pH, all other parameters (BOD₅, COD, TSS, TN, TP, and Coliform) exceeded the permissible limits, often by several-fold. The proportion of samples exceeding standards (excluding pH) was high, ranging from 30.0% to 92.86% for contract farms and from 86.67% to 96.67% for non-contract farms. A comparison between the two systems indicates that pollutant concentrations in the effluent of contract farms were consistently lower than those of non-contract farms. Specifically, average concentrations in contract farm effluents were 161 mg/L for BOD₅, 450 mg/L for COD, 145 mg/L for TSS, 133 mg/L for TN, and 17.67 mg/L for TP. These values were lower than those of non-contract farms by factors of 6.64 (1,069 mg/L), 4.16 (1,870 mg/L), 1.08 (157 mg/L), 2.42 (322.3 mg/L), and 3.92 (69.2 mg/L), respectively (Figure 2). Conversely, the average Coliform concentration in wastewater from contract farms (161,423 MPN/100 mL) was significantly higher—3.67 times greater—than that from non-contract farms (44,093 MPN/100 mL) (Table 5).

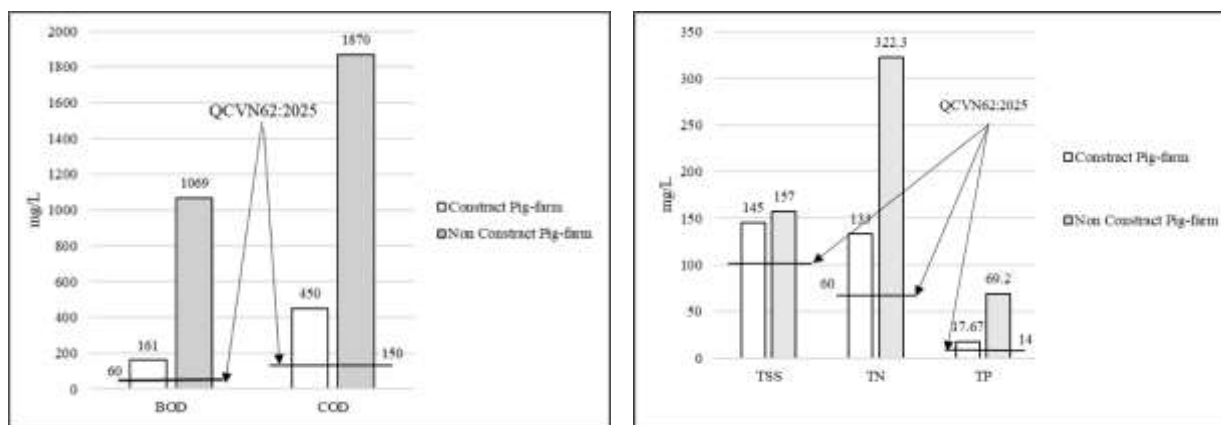


Figure 3: Comparison of pollutant concentrations in the effluent of contract and non-contract pig farms

Figure 3 confirms that both contract and non-contract pig farms failed to comply with wastewater quality requirements stipulated in QCVN 62:2025 of the Vietnamese Ministry of Agriculture and Environment. However, treatment efficiency was higher on contract farms, as reflected by lower exceedance rates and lower average concentrations of five out of six pollutant parameters compared with non-contract farms.

Thus, both types of pig farms in contract and non-contract failed to meet the wastewater quality requirements stipulated in QCVN 62:2025 of the Vietnamese Ministry of Agriculture and Environment. However, treatment efficiency was higher on contract farms, as reflected by lower exceedance rates and lower average concentrations of five out of six pollutant parameters compared with non-contract farms.

4.2. Water quality analysis results at pig farms

* Surface water

The results of surface water quality analysis around contract and non-contract pig farms are presented in Tables 5 and 6, respectively.

Table 5. Results of surface water quality analysis around contract pig farms

Parameter	X ± SD		QCVN08-2023 Column B	Percentage of samples not meeting QCVN08-2023 (%)		Percentage of samples not meeting QCVN08-2023 Column B	
	Dry season	Rainy season		Dry season	Rainy season	Difference	P-Value
pH	7.87 ± 0.60	8.0 ± 0.63	6.0 - 8.5	13.33	23.33	58	0.425169196
DO (mg/L)	6.35 ± 0.94	6.14 ± 0.66	≥ 4	6.67	3.33	52	0.326453319
BOD ₅ (mg/L)	39 ± 25	27 ± 15	< 6	96.67	100	47**	0.029494961
COD (mg/L)	61 ± 39	44 ± 24	< 15	96.67	96.67	48**	0.048009586
NH ₄ ⁺ (mg/L)	0.545 ± 0.968	0.894 ± 1.575	< 0.3	33.33	26.67	48	0.305797531
NO ₂ ⁻ (mg/L)	0.133 ± 0.379	0.141 ± 0.260	< 0.05	26.67	36.67	51	0.927483447
PO ₄ ³⁻ (mg/L)	0.300 ± 0.615	0.126 ± 0.124	< 0.2	33.33	23.33	31	0.139493995
TSS (mg/L)	38 ± 12	47 ± 14.3	< 100	0	0	57**	0.013161409
Coliform (MPN/100mL)	4,110 ± 2,265	2,270 ± 398	< 5000	26.67	0	31***	0.000124644

Note: (*), (**), (***) indicate statistical significance at the 10%, 5%, and 1% levels, respectively. QCVN 08:2023 - Column B: National Technical Regulation on Surface Water Quality - Column B (water quality ensuring aquatic life support).

Table 6. Results of surface water quality around non-contract pig farms

Parameter	X ± SD		QCVN08-2023 Column B	Percentage of samples meeting QCVN08-2023 (%)		Percentage of samples not meeting QCVN08-2023 Column B	
	Dry season	Rainy season		Dry season	Rainy season	Difference	P-Value
pH	7.92 ± 0.87	8.0 ± 0.88	6.0 - 8.5	23.81	26.19	82	0.706609501
DO (mg/L)	5.97 ± 1.16	6.18 ± 1.05	≥ 4	0	2.38	81	0.392402377
BOD ₅ (mg/L)	33 ± 35	21 ± 12	< 6	100	97.62	50*	0.050888911
COD (mg/L)	51 ± 52	37 ± 19	< 15	90.47	83.33	52*	0.099678006
NH ₄ ⁺ (mg/L)	0.700 ± 0.973	0.644 ± 1.217	< 0.3	50	26.19	78	0.817263379
NO ₂ ⁻ (mg/L)	0.051 ± 0.071	0.101 ± 0.249	< 0.05	26.19	30.95	48	0.220519484
PO ₄ ³⁻ (mg/L)	0.316 ± 0.671	0.128 ± 0.182	< 0.2	40.48	16.67	41***	0.007733
TSS (mg/L)	39 ± 10	51 ± 22	< 100	0	2.38	41***	4.78702E-18
Coliform (MPN/100mL)	5060 ± 6383	2286 ± 525	< 5000	28.57	0	42***	0.007550234

Note: (*), (**), (***) Note: (*), (**), (***) indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

QCVN08:2023- Column B: National Technical Standard for Surface Water Quality - Column B: Water Quality Ensuring Aquatic Life Support

Tables 5 and 6 show that surface water pH averaged 7.87 in the dry season and 8.0 in the rainy season around contract farms, while corresponding values in non-contract farm areas were 7.92 and 8.0, respectively. Average BOD₅ concentrations were 39 mg/L and 33 mg/L in the dry season and 27 mg/L and 21 mg/L in the rainy season for contract and non-contract farm areas, respectively. During the dry season, mean concentrations in contract versus non-contract areas were 61 mg/L and 51 mg/L for COD; 0.554 mg/L and 0.700 mg/L for NH₄⁺; 0.133 mg/L and 0.051 mg/L for NO₂⁻; 0.300 mg/L and 0.316 mg/L for PO₄³⁻; 38 mg/L and 39 mg/L for TSS; and 4,110 and 5,060 MPN/100 mL for Coliform. In the rainy season, the respective concentrations were 44 mg/L and 37 mg/L for COD; 0.894 mg/L and 0.644 mg/L for NH₄⁺; 0.141 mg/L and 0.101 mg/L for NO₂⁻; 0.126 mg/L and 0.128 mg/L for PO₄³⁻; 47 mg/L and 51 mg/L for TSS; and 2,270 and 2,286 MPN/100 mL for Coliform. Overall, pollutant concentrations in surface water tended to be higher in the dry season than in the rainy season in both farm types, except for NO₂⁻. Statistically significant seasonal differences were observed for BOD₅, COD, PO₄³⁻, TSS, and Coliform in both contract and non-contract farm areas.

* Groundwater

The results of groundwater quality analysis in contract and non-contract pig farming areas are presented in Table 7.

Table 7: Results of groundwater quality in contract and non-contract pig farming areas within the study area

Parameters	Contract Pig Farm (n = 70)				Non-Contract Pig Farm (n=30)			
	Dry season	Rainy season	Difference	P-Value	Dry season	Rainy season	difference	P-Value
pH	6.54 ± 0.54	6.62 ± 0.39	126	0.318407	6.02 ± 0.33	6.47 ± 0.44	54***	2.79852E-05

EC (mV)	264 ± 208	188 ± 154	127**	0.014998	136 ± 79	130 ± 110	53	0.810512461
NH ₄ ⁺ (mg/L)	0.31 ± 0.14	0.29 ± 0.14	138	0.487805	0.58 ± 0.50	0.55 ± 0.49	58	0.991074822
NO ₃ ⁻ (mg/L)	0.29 ± 0.37	0.21 ± 0.22	113	0.143611	0.12 ± 0.28	0.12 ± 0.16	47	0.948779239

Note: n = number of sampled farms; (*), (**), (***) indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 7 shows that the average pH of groundwater was 6.54 and 6.62 in the dry and rainy seasons, respectively, at contract farms, and 6.02 and 6.47, respectively, at non-contract farms. Electrical conductivity (EC) was 264 mV and 188 mV during the dry and rainy seasons at contract farms, compared with 136 mV and 130 mV, respectively, at non-contract farms. Inorganic nitrogen in groundwater primarily existed in the form of NH₄⁺, with average concentrations of 0.31 mg/L and 0.58 mg/L in the dry season and 0.29 mg/L and 0.55 mg/L in the rainy season at contract and non-contract farms, respectively. The average NO₃⁻ concentration was low, reaching 0.29 mg/L in the dry season and 0.37 mg/L in the rainy season at contract farms, compared with 0.12 mg/L in both seasons at non-contract farms. Overall, inorganic nitrogen concentrations in groundwater showed no statistically significant differences between contract and non-contract farms. Seasonal variations were minor, with slightly higher concentrations in the dry season than in the rainy season, but the differences were not significant.

5. DISCUSSION

5.1 Sources of waste

Solid and liquid waste from pig farms primarily consists of manure, urine, and pen wash water. These wastes are often mixed, forming a highly polluted waste stream. As shown in Table 4, pig farm wastewater contains large amounts of easily degradable organic matter, nitrogen, phosphorus, harmful microorganisms, and suspended solids. Consequently, pig farm wastewater is a major potential source of pollution, with serious impacts on surrounding surface water and groundwater (Ho Thi Lam Tra et al., 2016 [25]; Cao et al., 2021[26]). Survey results revealed that both contract and non-contract farms employ similar waste treatment systems, with biogas digesters as the central technology, supplemented by waste separation, composting, direct application or sale of solid manure, and biological ponds, lakes, or ditches. Although these systems significantly reduce pollutant concentrations in effluent, the effluent quality still fails to comply with QCVN 62:2025/BNNMT.

Although contract farms demonstrated better treatment efficiency (with lower pollutant concentrations in effluent), this advantage does not offset the impacts of the larger waste volumes generated. In fact, despite more advanced treatment, effluents from contract farms still fail to meet regulatory requirements, contributing to severe environmental pollution in surrounding surface water bodies (Hoa et al., 2024) [27]. Moreover, surface water pollution can increase the risk of groundwater contamination through infiltration and percolation, particularly of nitrogen compounds, which enhances groundwater pollution risks. Therefore, strict control of manure and wastewater generation at pig farms is essential to mitigate adverse impacts on the environment, especially water environment.

5.2 Assessment of the impact of pig farms on the water environment

* Surface water quality

Comparison with QCVN08:2023/BTNMT: According to QCVN 08:2023/BTNMT, the threshold values for surface water quality parameters are as follows: pH from 6.0 to 8.5, DO ≥ 4 mg/L, BOD₅ < 6 mg/L, COD < 15 mg/L, NH₄⁺ < 0.3 mg/L, NO₂⁻ < 0.05 mg/L, PO₄³⁻ < 0.2 mg/L, TSS < 100 mg/L, and Coliform < 5,000 MPN/100 mL. Comparison of surface water analysis results in contract farm areas (Table 5) and non-contract areas (Table 6) indicates that surface water in both systems was severely polluted. Average concentrations of BOD₅, COD, NH₄⁺, and NO₂⁻ frequently exceeded permissible thresholds during both rainy and dry seasons. In contract farm areas, exceedance rates were: pH (13.33% and 23.33%), DO (6.67% and 3.33%), BOD₅ (96.67% and 100%), NH₄⁺ (33.33% and 26.67%), NO₂⁻ (26.67% and 36.67%), PO₄³⁻

(33.33% and 23.33%), and Coliform (26.67% and 0%) in the dry and rainy seasons, respectively (Table 5). The highest and most frequent exceedances occurred for BOD₅ and COD, with rates above 90%. Overall, exceedance rates were higher in the dry season than in the rainy season. Similarly, in non-contract farm areas, exceedance rates were also very high: BOD₅ (100% and 97.62%), COD (90.47% and 83.33%), NH₄⁺ (50% and 26.19%), NO₂⁻ (26.19% and 30.95%), PO₄³⁻ (40.48% and 16.67%), and Coliform (28.87% and 0%) in the dry and rainy seasons, respectively. Again, exceedance frequencies were consistently higher in the dry season. These findings align with reported evidence of water pollution in pig farming areas in Vietnam (Ho Thi Lam Tra et al., 2016; Cao et al., 2021; Hoa et al., 2024) [25, 26, 27].

Comprehensive Water Pollution Index – CPI: The calculated CPI values for surface water around contract and non-contract pig farms are presented in Table 8. In the dry season, CPI values were 2.53 and 2.18, while in the rainy season they were 2.11 and 1.69 for contract and non-contract farms, respectively. These values classify surface water in contract farm areas as heavily polluted in both seasons, while non-contract farm areas ranged from moderately to heavily polluted. No clean or fairly clean water quality was observed in either system. In contract farm areas, heavy pollution accounted for 56.67% and 40.00% of sites in the dry and rainy seasons, followed by moderate pollution (36.67% and 36.67%) and light pollution (6.67% and 23.33%). In non-contract areas, moderate pollution dominated (46.67% and 44.44%), followed by heavy pollution (35.56% and 20.00%) and light pollution (11.11% and 28.89%) in the dry and rainy seasons, respectively.

Thus, CPI results confirm that surface water in both contract and non-contract pig farming areas was severely affected, with pollution levels consistently higher in the dry season. These findings are consistent with comparisons of surface water pollutant concentrations against QCVN 08:2023/BTNMT.

Table 8. Calculation results of the CPI index of surface water at pig farms in the study area

CPI	Water polluted level	Contract Pig-farm				Non Contract Pig-farm			
		Dry season		Rainy season		Dry season		Rainy season	
		Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)
< 0.2	Clean	0	0	0	0	0	0	0	0
0.2 - 0.4	Sub clean	0	0	0	0	0	0	0	0
0.4 - 1.0	Slightly polluted	2	6.67	7	23.33	5	11.11	13	28.89
1.0 - 2.0	Medium polluted	11	36.67	11	36.67	21	46.67	20	44.44
>2.0	Heavily polluted	17	56.67	12	40.00	16	35.56	9	20.00
Mean of CPI Value ± SD		2.53 ± 1.43		2.11 ± 1.61		2.18 ± 1.53		1.69 ± 1.26	

* Groundwater quality

Comparison with QCVN 09:2023/BTNMT: According to QCVN 09:2023/BTNMT – Vietnam’s National Technical Regulation on Groundwater Quality, the permissible thresholds are pH = 6.0–8.5, NH₄⁺ = 1.0 mg/L, and NO₃⁻ = 15 mg/L. Comparison of analytical results from contract and non-contract pig farms with these thresholds indicates that pollutant concentrations remained below the permissible limits. This suggests that groundwater quality at both contract and non-contract farms is still good and has not been significantly affected.

CPI index in groundwater: Results of the groundwater CPI index (Table 9) show that groundwater quality in both contract and non-contract farming areas was classified as clean or very clean in both seasons. In contract farm areas, clean water accounted for the highest proportion (27.86% and 84.29%), followed by fairly clean water (27.14% and 15.71%) in the dry and rainy seasons, respectively. In non-contract areas, clean water accounted for 50.00% and 100.00% of samples, while fairly clean water accounted for 13.33% and 0%, and slightly polluted water accounted for 36.67% and 0% in the dry and rainy seasons, respectively.

Thus, groundwater quality in pig farming areas showed little evidence of pollution. Only a few non-contract farms exhibited slight pollution by NH₄⁺ in the dry season (36.67%).

Table 9: Calculation results of the CPI index of groundwater contract and non-contract pig farms in the study area

CPI	Water pollution level	Contract Pig Farm				Non-Contract Pig Farm			
		Dry season		Rainy season		Dry season		Rainy season	
		Number	Ratio (%)	Number	Percentage (%)	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	Moderately polluted	0	0	0	0	0	0	0	0
> 2.0	Heavily polluted	0	0	0	0	0	0	0	0
Mean CPI Value ± SD		0.16 ± 0.07***		0.15 ± 0.07***		0.30 ± 0.25***		1.69 ± 1.26***	

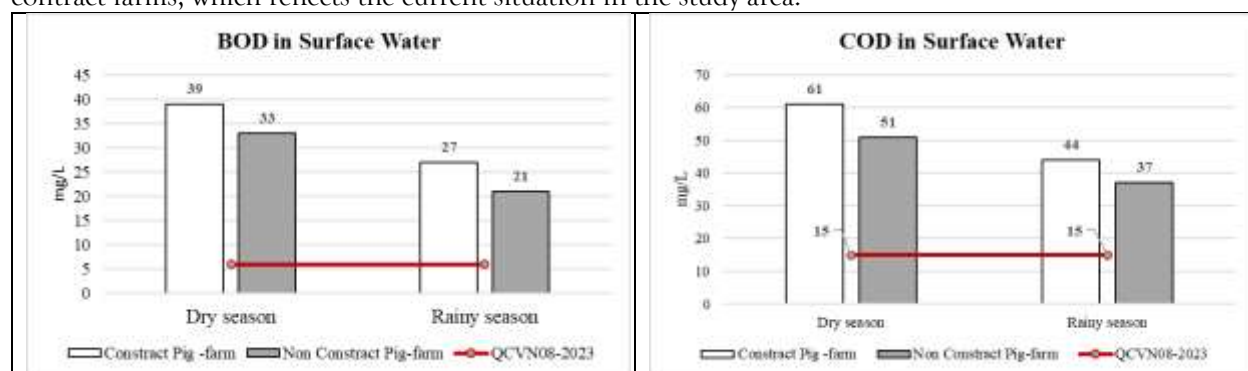
Note: (*), (**), (***) indicate statistical significance at the 10%, 5%, and 1% levels, respectively

By comparing water quality analyses and CPI index results, it can be concluded that pig farms, whether contract or non-contract, exert significant impacts on surface water quality, causing substantial pollution. In contrast, the impact on groundwater was less evident, as only a small proportion of non-contract farms (36.67%) exhibited slightly polluted groundwater during the dry season. Overall, the impact of pig farms on the water environment was markedly greater in the dry season than in the rainy season.

5.3. Comparison of the impact on the water environment between contract and non-contract pig farms

* Impact on surface water

Both the comparison of surface water quality against QCVN 08:2023/BTNMT and the CPI results indicate that pollution levels in surface water surrounding contract farms were higher than those around non-contract farms (Figure 4). This finding appears to contradict the initial assumption that waste management at contract farms is better financed, prioritized, and implemented than at non-contract farms (Huong et al., 2020) [12]. In this study, analysis of effluent from livestock farms confirmed that treatment efficiency was indeed higher at contract farms than at non-contract farms (Table 4). Moreover, contract farms had larger areas, allowing more space for environmental treatment facilities (Table 3). However, the overall assessment showed that contract farms exerted a significantly greater impact on surface water quality than non-contract farms. The primary reason is scale: contract farms typically raise 3.14 times more pigs per farm. A larger herd size leads to a greater volume of waste, meaning that average waste discharge per contract farm is approximately three times that of a non-contract farm. Furthermore, although treatment efficiency was higher, pollutant concentrations in effluent from contract farms still failed to meet QCVN 62:2025/BNNMT requirements, with 100% of surveyed farms exceeding at least one parameter (Table 4). Therefore, it is evident that contract pig farms negatively affect the surrounding water environment and cause more severe pollution than non-contract farms, which reflects the current situation in the study area.



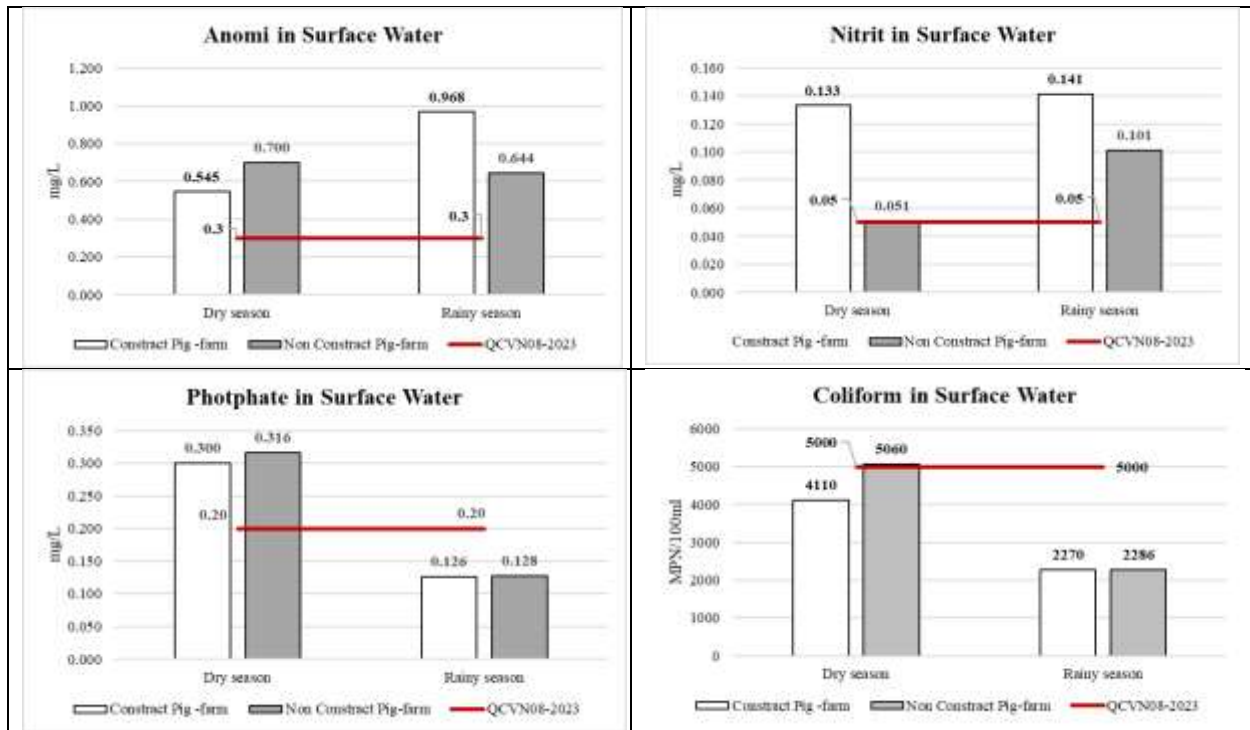


Figure 4. Comparison of major pollutant concentrations in surface water surrounding contract and non-contract pig farms

* Impact on groundwater

Groundwater pollution in pig farming areas, particularly contamination by inorganic nitrogen, has been widely documented by both domestic and international researchers (Tra et al., 2010 [8]; Ho Thi Lam Tra et al., 2016 [20]). This is primarily due to pig manure and wastewater containing large amounts of easily degradable nitrogen compounds, which can infiltrate soil layers, reach aquifers, and cause groundwater pollution. However, analysis of groundwater samples from the 100 surveyed farms, together with CPI index results, indicates that groundwater quality in the study area remains generally good. In contract farming areas, all groundwater samples were classified as clean or fairly clean during both rainy and dry seasons. Average concentrations of pollutants were also below the limits specified by QCVN 09:2023/BTNMT. These results suggest that contract farms have not significantly affected groundwater quality. In contrast, at non-contract farms, although mean pollutant concentrations also remained below permissible thresholds, some farms exhibited NH_4^+ contamination during the dry season. Specifically, 36.67% of non-contract farms were classified as having slightly polluted groundwater. In other words, the impact on groundwater quality was more evident in non-contract farms than in contract farms, highlighting the need for closer monitoring and management.

6. CONCLUSION

This study has shown that contract pig-farms are having a major impact on the quality of surrounding surface water when the concentrations of pollutants such as BOD_5 , COD, NH_4^+ , NO_2 , PO_4^{3-} are all much higher than QCVN08:2023 - National technical regulation on surface water quality of Vietnam. At the same time, the CPI index in surface water is always high with 56.67% and 40% of farms classified as heavily polluted; 36.67% and 36.67% classified as moderately polluted and 6.67% - 23.23% as lightly polluted in the dry and rainy seasons, respectively. The impact level of contract pig-farms was higher than that of non-contract pig-farms used as controls in this study. The main reason is that the scale of pig-farms with contracts is 3.14 times higher than that of pig-farms without contracts, so the source of waste generated into the environment is larger. Although the waste treatment efficiency of contracted pig farms was better than that of non-contracted pig farms (average concentrations of pollutants in the effluent were lower than that of non-contracted farms). For

groundwater, the impact of contracted pig farms is insignificant when the concentrations of surveyed pollutants (NH_4^+ and NO_3^-) are all below the allowable threshold of QCVN09-2023/BTNMT - National technical regulation on groundwater quality of Vietnam. On the other hand, the CPI index in groundwater of contracted farms is always low, within the clean water level (72.86% in the dry season and 84.29 in the rainy season) and quite clean (27.14% in the dry season and 15.71 in the rainy season).

The study also showed that surface water quality in both contract and non-contract pig-farm areas was seriously polluted. The reason is that the current waste treatment system of pig farms is not guaranteed, 100% of the output wastewater samples of the farms do not meet QCVN62-MT:2025 - National technical regulation on livestock wastewater of Vietnam. Therefore, to address this reality, the Vietnamese Government needs to soon take measures to more effectively control waste sources generated from pig farms as follows: Convert pig farms to waste recycling farms to minimize waste generation into the environment; Promote the application of highly efficient livestock waste treatment technologies; and increase the effectiveness of pollution control through economic measures such as environmental fees and carbon taxes on pig farms.

Although this study has shown the impact of contract pig-farms on water quality (surface water and groundwater), the study has not yet analyzed in depth the factors that create differences in the impact of these types of pig-farms compared to non-contract pig-farms. No specific solutions have been proposed to minimize the impact of contract pig farms on water quality. This is a limitation that needs to be focused on and resolved in the coming time.

Author Contributions:

Bui Phung Khanh Hoa formed the research idea, supervised the research, collected and analyzed the data, and drafted the manuscript. Tran Trong Phuong, Nguyen Hai Nui, Tran Thi Thanh Huyen and Le Xuan Sinh commented and edited on the manuscript. Le Thu Huong and Cao Truong Son supervised the research, commented, and edited the manuscript. All authors read and approved the final manuscript.

Funding: This research funding by The project: “Developing Technical Guidelines for Using Livestock Wastewater after Biogas Projects to Meet QCVN01-195/2022/BNNPTNT for Irrigation of Crop Plant”, Ministry of Agriculture and Environment 2025 – 2027.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

- [1]. Turner, K., Georgiou, S., Clark, R., Brouwer, R. & Burke, J. 2004. Economic Valuation of water resources in agriculture, From the sectoral to a functional perspective of natural resource management. FAO paper reports No. 27, Rome, FAO. <https://www.fao.org/4/y5582e/y5582e00.htm#Contents>
- [2]. FAO. (2006). Livestock's long shadow: Environmental issues and options. Rome: FAO. <https://www.fao.org/4/a0701e/a0701e00.htm>
- [3]. Zhang, N.; Liu, W.; Peng, Y.; Song, X. Anaerobic Membrane Bioreactors for Livestock Wastewater Treatment and Resource Recovery: Opportunities and Challenges. *Curr. Pollut. Rep.* 2021
- [4]. Sun, L.; Zhao, H.; Liu, J.; Li, B.; Chang, Y.; Yao, D. A New Green Model for the Bioremediation and Resource Utilization of Livestock Wastewater. *Int. J. Environ.* 2021, 18, 8634. <https://doi.org/10.3390/ijerph18168634>
- [5]. Li, X., Liu, Y., Chen, D., Xu, J., & Zhang, L. (2022). Multi-pollutant assessment of river pollution from livestock production. *Water Research*, 209, 117905. <https://doi.org/10.1016/j.watres.2021.117905>
- [6]. Mohammadi, S., Yolcubal, I., Şener, A., & Güneş, K. (2023). The impact of livestock activities and geochemical processes on groundwater quality of fractured volcanic aquifer: Lake Çıldır watershed (NE Turkey). *Environmental Monitoring and Assessment*, 195(5), 436. <https://doi.org/10.1007/s10661-023-11016-z>
- [7]. Pedrozo-Acuña, A., González-Cevallos, N., & Díaz-Delgado, C. (2025). Water sustainability criteria to regulate the proliferation of pig farms on a karst aquifer, Yucatan, Mexico. *Sustainability*, 17(7), 3069. <https://doi.org/10.3390/su17073069>
- [8]. Tra H. T. L., Son C. T., Loan T. T., Kurosawa K., and Egashira K. (2010). “Assessment of Surface and Groundwater Quality in Pig-raising Villages of Haiduong Province in Vietnam”. *Journal of the Faculty of Agriculture, Kyushu University, Japan*, 55(1), 123-130.
- [9]. Tra H. T. L., Son C. T., Anh L. D., Ton V. D., Kurosawa K., and Egashira K. (2013). “Evaluation of Water Pollution Caused by Different Pig-Farming Systems in Hungyen Province of Vietnam”. *Journal of the Faculty of Agriculture, Kyushu University, Japan*, 58(1), 159-165.
- [10]. Tra H. T. L., Son C. T., Hoa B. P. K., and Nui N. H. (2016). “Comparison of Two Pig-Farming Systems in Impact on The Quality of Surface and Groundwater in Hanoi, Vietnam”. *International Journal of Agriculture Innovations and Research*, 5(1), 11-19

- [11]. Huong, L. T. T., Takahashi, Y., Duy, L. V., Son, C. T., Chung, D. K., & Yabe, M. (2021). Wastewater treatment efficiency of small and large-scale pig farms in Vietnam. *Journal of the Faculty of Agriculture, Kyushu University*, 66(2), 291–297. <https://doi.org/10.15017/4486561>
- [12]. Costales, A., Son, N., Lapar, M., Tiongco, M. (2006). Smallholder Contract Farming of Swine in Northern Viet Nam: Contract Types.
- [13]. Ogishi, A., Zilberman, D., Metcalfe, M., 2003. Integrated agribusinesses and liability for animal waste. *Environ. Sci. Pol.* 6 (2), 181–188. [https://doi.org/10.1016/S1462-9011\(03\)00007-8](https://doi.org/10.1016/S1462-9011(03)00007-8).
- [14]. Costales, A., Catelo, M., 2008. Contract farming as an institution for integrating rural small-holders in markets for livestock products in developing countries: (I) framework and applications. Pro-Poor Livestock Policy Initiative (PPLPI) Research Report. FAO.
- [15]. Menezes, A., Ridler, N., Murekezi, P., 2018. Contract Farming and Public–Private Partnerships in Aquaculture. Lessons Learned From East African Countries. Food and Agriculture Organization of the United Nations.
- [16]. Delgado, C.L., Narrod, C.A., Tiongco, M.M., de Camargo Barros, G.S.A., 2008. Determinants and implications of the growing scale of livestock farms in four fast-growing developing countries. *Intl Food Policy Res Inst.* 157.
- [17]. Huong, L. T. T., Son, N. T., Luan, P. D., Dung, N. T., & Egashira, K. (2020). Manure management and pollution levels between contract and non-contract livestock farming in Vietnam. Oral presentation at International Workshop, Vietnam National University of Agriculture.
- [18]. Hanoi City Statistical Office (2025). Hanoi City Statistical Yearbook 2024. Statistical Publishing House (In Vietnamese).
- [19]. American Public Health Association (1992). Standard method for examination of water and waste water. 18th edition, 1992, Washington D.C.
- [20]. Cataldo, D. A., M. Haroon, L. E. Schrader and V. L. Youngs (1975). Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Communications in Soil Science and Plant Analysis*, 6, 1975, pp. 71-80.
- [21]. ISO (1989). Water quality-Determination of biochemical oxygen demand after 5 days (BOD5)- Dilution and seeding method, 1989
- [22]. ISO 11923-1997 (1997). Water quality - Determination of suspended solids by filtration through glass-fibre filters, 1997.
- [23]. ISO 9308-1990 (1990). Water quality - Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive *Escherichia coli* - Part 1: Membrane filtration method, 1990.
- [24]. Matta, G., Kumar, A., Uniyal, D. P., Singh, P., Kumar, A., Dhingra, G. K., Ajendra, K., Naik, P. K. & Shrivastva, N. G. (2017). Temporal assessment using WQI of River Henwal, a Tributary of River Ganga in Himalayan Region. *Int. J. Environ. Rehabil. Conserv.* 8 (1), 187–204.
- [25]. Ho Thi Lam Tra, Cao Truong Son, Nguyen Hai Nui, Bui Phung Khanh Hoa (2016). Comparison of two pig-farming systems in impact on surface and groundwater quality in Hanoi, Vietnam. *International Journal of Agricultural Innovations and Research (IJAIR)*. Volume 5, Issue 1, pp 11-19.
- [26]. Cao ST, Tran HP, Le HTT, Bui HPK, Nguyen GTH, Nguyen LT, Nguyen BT, Luong AD. Impacts of effluent from different livestock farm types (pig, cow, and poultry) on surrounding water quality: a comprehensive assessment using individual parameter evaluation method and water quality indices. *Environ Sci Pollut Res Int.* 2021 Sep;28(36):50302-50315. doi: 10.1007/s11356-021-14284-9. Epub 2021 May 6. PMID: 33959840.
- [27]. Hoa B. P. K., Son C.T., Huong L.T.T., Van D.T.H., Phuong T.T., Vien T.D. (2024). Chapter 6: Circular agriculture: The way towards sustainable development of pig – farming systems in Vietnam. In *Advance in Environmental research*. Nova Science Publishers, Inc