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RESEARCH ARTICLE

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

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Abstract

Water pollution within and nearby different livestock farm types was assessed comprehensively for the first time in Vietnam. The samples of wastewater, ground water, and surface water were collected from 130 pig farms, 80 poultry farms, and 40 cow farms. Water quality was first assessed by individual parameter evaluation method in which measured values of water quality parameters were compared with the permissible limits in the national technical regulations on livestock's effluent (QCVN 62), surface water quality, and ground water quality. Subsequently, the overall quality of surface and ground water samples was evaluated by mean of water quality index (WQI). The results showed the large variations in effluent's quality, implying the considerable differences in wastewater treatment efficiency within and among farm types. Effluent from livestock farms was highly polluted by organic matters (expressed as BOD_5 and COD) and especially by microorganisms (expressed as total coliform—CF). Almost all wastewater samples contained higher number of CF than QCVN 62 (3900 MPN/100ml), with mean concentration of CF in effluent from cow farms, pig farms, and poultry farms were 1.2e+07 ± 5.0e+07 MPN/100ml, 8.8e+04 ± 7.1e+04 MPN/100ml, 1.5e+06 ± 4.2e+06 MPN/100ml, respectively. Improperly treated livestock's waste was likely to have impacts on quality of ground water and receiving surface water bodies. High CF contamination in effluent leads to 70% of the ground water samples in cow farms and poultry farms classified as unsuitable for drinking water supply by WQI values. Although effluent from poultry farms had smaller quantity and better quality, their receiving surface water bodies exhibited the worst quality, with average WQI of 37.5 ± 16.2 compared to 49.9 ± 12 of pig farms and 50.3 ± 20.8 of cow farms. This result suggests that livestock's effluent was not only pollution source of surface water bodies nearby livestock farms.

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Introduction

Livestock production is one of the fastest growing agricultural subsectors, especially in developing countries. Animal products in general and meat, milk, eggs from livestock production in particular are important sources of high-quality protein for human consumption. Livestock products account for 33% of global protein consumption (Thornton 2010). They also provide humans with diverse essential micronutrients (e.g., vitamins, iron, zinc) (Reynolds et al. 2015; Scanes 2018a). Furthermore, increasing world population and living standard have resulted in a dramatical rising in demand for livestock products (Thornton 2010; Ogbuewu et al. 2012). As summarized in Henchion et al. (2014), the global poultry meat consumption has been doubled from 40.2 Mt in 1990 to 105.5 Mt in 2010, while that of pork increased by 53.6% during the same period. The consumption of bovine meat was quite stable with an average annual growth rate of about 1%. The global demand for meat is projected to be 465 Mt/year in 2050 (Dopelt et al. 2019).

Along with increasing demand on meat and other livestock products, there were well-recognized environmental impacts associated with the livestock production: water, air, and soil pollution, consumption of natural resources, and global warming (Steinfeld et al. 2006; Martinez et al. 2009; Scanes 2018b). Livestock sector is considered as one of the top three contributors to the main environmental problems worldwide, including water pollution (Mateo-Sagasta et al. 2018). At the farm level, livestock production generates a large amount of manure and wastewater, which usually contain high concentration of pollutants, e.g., nutrients (nitrogen and phosphorus compounds), organic matters, heavy metals, and pharmaceutical residues (Hooda et al. 2000; Tullo et al. 2019). These wastes once discharged into surrounding water bodies or spread on soil can result in the degradation of surface and ground water quality (Steinfeld et al. 2006; Infascelli et al. 2009; McAllister and Topp 2012; Ogbuewu et al. 2012; Sahoo et al. 2016).

In Vietnam, livestock production is an important agricultural subsector, contributing about 28% of agricultural gross value added (Dinh 2017). It has experienced a rapid growth during the last decade, with the amount of slaughtered livestock animals (i.e., beef, pork, and poultry) increased from 3.53 million tons in 2008 to 5.17 million tons in 2017 (GSO 2018). The pig and cow populations were stable during the same period, while there was a significant growth of poultry population with the average annual growth rate of 6.1%. There was also a shift in livestock production systems from traditional extensive small householder farms to semi-industrial and industrial intensive farms. There have been many established concentrated livestock production areas in main cities of Vietnam, e.g., Hanoi and Ho Chi Minh City. For example, the number of livestock farms in Hanoi (the capital of Vietnam) has increased from 1123 farms in 2011 to 2733 farms in 2018, accounting for nearly 14% of total livestock farms in Vietnam (GSO 2018). This trend is also observed in many other countries with the increased demand for fresh meat, milk, and egg within prospering urban centers and lack of efficient infrastructure in rural areas resulting in a large concentration of livestock production in proximity of populated cities (Gerber et al. 2005). One of the noticed features of these intensive livestock production systems is the gathering of large number of animals in relatively small areas, leading to increasing risk of environmental pollution problems (Kornboonraksa et al. 2009; Bernet and Béline 2009). There is a huge amount of animal manure generated in Vietnam (about 80 million tons/year), in which pigs, poultry, and cattle account for the respective proportions of 30%, 29%, and 23% (Dinh 2017). As of 2015, a large proportion (36%) of generated manure and wastewater from livestock farms (40% of smallholder farms and 16% of intensive farms) was discharged directly into the environment without proper treatment, which is likely to cause the serious environmental impacts, especially water pollution.

Ho et al. (2013) found that surface water around pig farms in Hung Yen province was heavily polluted by organic matters and nutrients. The BOD_5 and COD content exceeded the permissible limits in national technical regulation on surface water quality (QCVN 08) by up to 91 and 58 times, respectively. Concentrations of NH_4^+-N and PO_4^{3-}-P were up to 106 and 35 times higher than the permissible limits. The ground water in these farms was heavily polluted by NH_4^+-N with average concentration ranging from 3.29 to 10.93 mg/l, which is three to eleven times higher than the permissible limit of 1 mg/l in the national technical regulation on ground water quality (QCVN 09). The ground water pollution caused by NH_4^+-N was also found in some pig farms of Hai Duong province and Hanoi with average NH_4^+-N concentration of 2.65–5.5 mg/l and 0.05–5.22 mg/l, respectively (Ho et al. 2010; Nguyen et al. 2015). Water pollution levels were largely dependent on types of pig farm (Ho et al. 2013). As such, some studies have been conducted to assess the water pollution from livestock production in Vietnam, but merely focused on pig farms. To our best of knowledge, there were no such similar researches for poultry and cow farms in the country, which are also very important parts of livestock husbandry of Vietnam. Furthermore, all above existing studies applied an individual parameter evaluation method, in which measured values of water quality parameters are compared with their permissible limits in national environmental standards to determine the water quality and/or applicability. There are also comprehensive evaluation methods, i.e., so-called water quality indices (WQIs), which can be used to assess the overall water quality status (Tirkey et al. 2013; Li and Liu 2019). The WQIs are dimensionless single numbers calculated from the large number of measured physio-chemical and biological water quality parameters. They provide policy makers and the public with the non-technical, more understandable, and synthesized information about water quality (Swamee and Tyagi 2007; Walsh and Wheeler 2012; Tyagi et al. 2013; Rocha et al. 2014; Sutadian et al. 2015). WQIs are easier and quicker to understand than a list of many numerical values of water quality parameters (Pham et al. 2011; Rocha et al. 2014). They have been widely used to evaluate overall water quality of both surface water and ground water (Lumb et al. 2011; Balan et al. 2012; Dhanasekar and Partheeban 2014; Sutadian et al. 2015).

This study aims to comprehensively assess the water pollution (including wastewater effluent, surface water, and ground water) within and near different livestock farm types, i.e., pig farms, poultry farms, and cow farms in Vietnam. The water quality was assessed by both individual parameter evaluation method using the national technical regulations on water quality and WQIs. The study results are expected to provide valuable information to support the future environmental management planning and improve the quality of water environment in concentrated livestock production areas in Vietnam.

Materials and methods

Study area

Hanoi has the largest livestock herds with the number of cows, pigs, and poultries that are of 136,000, 1,635,900, and 25,620,000 heads, respectively (GSO 2018). Therefore, it was chosen as a representative for livestock production in Vietnam. Livestock farms here are concentrated near populated residential areas; hence, it is likely to cause more severe water-related environmental problems. Our study focused on assessing water pollution within and near livestock farms in peri-urban districts of Hanoi, which has been planned to build concentrated livestock production areas. The water sampling scheme is represented in Fig. 1 and details on locations of livestock farms can be found in Supporting Information 2.

Water sampling and analysis

Water samples were collected from 250 livestock farms from 20 September 2019 to 30 September 2019, following Vietnam National Standards (TCVN) on water sampling, including TCVN 6663-11:2011 (Water quality - Sampling - Part 1: Guidance on the design of sampling programs and sampling techniques), TCVN 5999:1995 (Water quality - Sampling - Guidance on sampling of waste water), TCVN 6663-6:2018 (Water quality - Sampling Part 6: Guidance on sampling of rivers and streams), TCVN 6663-11:2011 (Water quality - Sampling - Part 11: Guidance on sampling of groundwaters). At each farm, 3 water samples were collected, including wastewater effluent, surface water, and ground water samples. Wastewater samples were collected at the end of the livestock farms' wastewater treatment systems before being discharged into the sewers and/or receiving water bodies. Surface water samples were taken at a depth of about 15–30 cm in the receiving water body (i.e., ponds, lakes, canals, rivers, streams). Ground water samples were collected from tube/peach wells in the livestock farms. Detail description of analyzed water quality parameters and analytical methods is presented in Table 1. Water samples were preserved and sent to laboratories for analysis according to TCVN 6663-3: 2011 (Water quality - Sampling - Part 3: Guidance on the preservation and handling of water samples). Water samples were analyzed in the standard laboratories of An Binh Tec., JSC and Environment Analyzing and Technique., JSC.

Assessment of water quality using national technical regulations

The results from water analysis were compared with the Vietnamese national technical regulations on water quality issued by Ministry of Natural Resource and Environment (MONRE), including:

- QCVN 62-MT:2016/BTNMT (herein QCVN 62)—national technical regulation on the effluent of livestock (MONRE 2016)
- QCVN 08-MT:2015/BTNMT (herein QCVN 08)—national technical regulation on surface water quality (MONRE 2015a).
- QCVN 09-MT:2015/BTNMT (herein QCVN 09)—national technical regulation on ground water quality (MONRE 2015b).

QCVN 62 is the national technical regulation which is used to assess the compliance of wastewater effluent with the legal requirement. It stipulates the permissible limits of pH, BOD_5, COD, TN-N, and CF of livestock farms' wastewater effluent before being discharged into general sewers or receiving water bodies. Although TP-P is not included in QCVN 62, we compared the measured values with the permissible limits of effluent from aquatic products processing industry (QCVN 11). These permissible limits are calculated from 3 parameters: (i) the basic concentrations of wastewater discharged into water

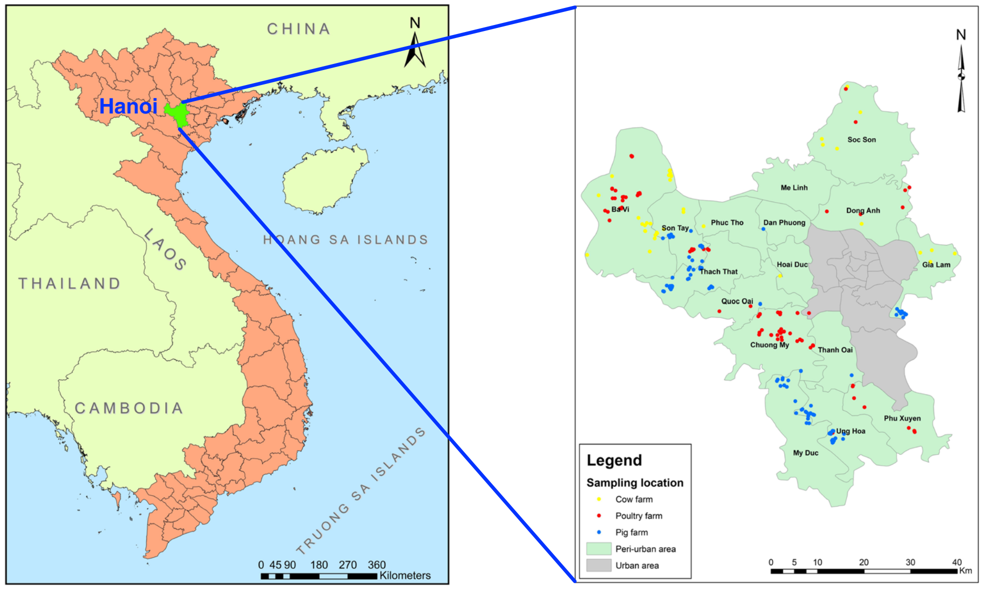

Fig. 1 Study area and sampling locations

bodies (category B) which are used for non-drinking purpose; (ii) the coefficient of receiving water body ($K_q = 0.6$); and (iii) the coefficient of effluent discharge rate ($K_f = 1.0$). QCVN 08 and QCVN 09 are two national technical regulations on quality of the surrounding environment. They are used to assess if the surrounding water environment (i.e., surface water and ground water) is polluted or not. Regarding surface water, there are different permissible limits for each water quality parameters. They are used to assess the quality of a surface water body according to the consumption purposes (i.e., drinking water supply—categories A1 and A2, irrigation—category B1, transportation—category B2). In this study, we applied the category B1 in QCVN 08, which is used to assess if water quality meets the requirements for irrigation. Details on permissible limits of water quality parameters can be found in Supporting Information 1.

Assessment of overall water quality using water quality index

Surface water

The Vietnam Environment Administration (VEA) agency has issued Decision No. 1460/QĐ-TCMT on the technical guidelines for calculating water quality index (WQI) (VEA 2019). WQI is used to assess the overall quality of surface water.

Table 1 Water quality parameters and analytical methods

No.	Parameters	Symbols	Unit	Analytical methods	Surface water	Ground water	Waste water
1	pH	pH	-	ISO 10523 : 2008	x		
2	Dissolved oxygen	DO	mg/L	ISO 5814:12012	x		
3	Biological oxygen demand (5 days)	BOD_5	mg/L	ISO 5815-1 : 2003	x		x
4	Chemical oxygen demand	COD	mg/L	SMEWW 5220- C:2017	x	x	x
5	Total suspended solid	TSS	mg/L	ISO 11923 : 1997	x		x
6	Total coliform	CF	MPN/100ml	ISO 9308-2: 1990	x	x	x
7	Ammonium-nitrogen	NH_4^+-N	mg/L	SMEWW 4500-NH3.B&F:2012	x	x	
8	Nitrate-nitrogen	NO_3^--N	mg/L	SMEWW 4500-NO_3^-. D:2017	x	x	
9	Phosphate-phosphorus	PO_4^{3-}-P	mg/L	SMEWW 4500-P. E:2017	x		
10	Total nitrogen	TN-N	mg/L	ISO 10048 : 1991			x
11	Total phosphorus	TP-P	mg/L	SMEWW 4500-P.B&E:2017			x
12	Heavy metals	As, Cu, Zn, Pb	mg/L	SMEWW 3111.B:2017		x	

ISO, International Standardization Organization; *SMEWW*, Standard Method for Examination of Water and Wastewater; *x*, stand for analyzed parameters in each type of water samples

Water quality parameters are divided into 5 groups: (1) pH, (2) pesticides (Aldrin, Benzene hexachloride—BHC, Dieldrin, DDTs, Heptachlorine and Heptachlor epoxide), (3) heavy metals (As, Cd, Pb, Cr^{6+}, Cu, Zn, Hg), (4) organic matters and nutrients (DO, BOD_5, COD, TOC, NH_4^+-N, NO_3^--N, NO_2^--N, PO_4^{3-}-P), and (5) microorganisms (coliform, E. coli). Based on measured value of the water quality parameters, sub-indices (WQI_{SI}) for each parameter are calculated. Details on calculation of these sub-indices can be found in Supporting Information 1. The overall water quality index (WQI) will be then calculated as follows:

$$WQI = \frac{WQI_{pH}}{100} \times \frac{\left(\prod_{i=1}^{n} WQI_{2,i}\right)^{1/n}}{100} \times \frac{\left(\prod_{i=1}^{m} WQI_{3,i}\right)^{1/m}}{100} \times \left[\left(\frac{1}{k}\sum_{i=1}^{k} WQI_{4,i}\right)^{2} \times \frac{1}{l}\sum_{i=1}^{l} WQI_{5,i}\right]^{1/3} \quad (1)$$

$WQI_{2,i}$, $QWI_{3,i}$, $WQI_{4,i}$, $WQI_{5,i}$ are the sub-indices for water quality parameters in groups 2, 3, 4, and 5 respectively; n, m, i, and l are the number of considered parameters in the corresponding groups.

Note that data used to calculate WQI of surface water need to consist of minimum 3 groups of water quality parameters in which the presence of group 4 is compulsory. Moreover, at least 3 parameters in group 4 are required as minimum (VEA 2019).

There was lack of data on temperature of surface water samples; hence, we assumed that the temperature of water sample was 30°C (mean average temperature during the sampling period). The robustness of this assumption was analyzed by sensitivity analysis in which temperature was allowed for varying by ±20%.

The WQI of surface water samples ranges from 0 to 100; the higher WQI represents, the better water quality. The result of WQI calculation will be used to evaluate the surface water quality based on classification specified in Decision No. 1460/QĐ-TCMT (VEA 2019) (Table 2).

Ground water

There was no existing water quality index issued by authority in Vietnam for ground water quality assessment. In this study, the overall ground water quality was evaluated by using the weighted arithmetic water quality index (Tyagi et al. 2013).

$$WQI = \frac{\sum_{i=1}^{n} Q_i \times W_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

where Q_i and W_i are the quality rating scale and the weighting factor for each parameter. They were calculated by using the following equations:

$$Q_i = 100\frac{V_i}{S_i} \quad (3)$$

where V_i and S_i are the measured value and permissible limit in the national technical regulation on ground water quality (QCVN 09) of the parameter ith, respectively.

$$W_i = \frac{K}{S_i} \quad (4)$$

where K is the proportionality constant and can be calculated by the following equation:

$$K = \frac{1}{\sum_{i=1}^{n}\frac{1}{S_i}} \quad (5)$$

n is the number of considered parameters.

Based on the calculated WQI values, the quality of ground water can be classified as in Table 3.

The contribution of each water quality parameter on WQI of ground water samples was assessed by using the effective weight index (Ibrahim 2019).

$$EW_i = \frac{W_i \times Q_i}{WQI} \times 100 \quad (6)$$

where EW_i is the effective weight of the ith water quality parameter.

Statistical analysis

Some basic descriptive statistics of the water quality data and WQIs have been calculated including arithmetic mean, standard deviation (SD), median, and coefficient of variation (CV). The arithmetic mean (or median) and standard deviation, which are the measures of central tendency and dispersion, respectively, were employed to summarize data. The CV is the standardized measure of dispersion, which is defined as the ratio of standard deviation to the mean (expressed as percentage). It is useful when comparing dispersion of data sets with widely different means.

The differences in means of water quality parameters and WQIs among livestock farm types were analyzed by using the analysis of variance (ANOVA). There are two main important assumptions of ANOVA, i.e., (i) normality and (ii) homogeneity of variance of the residuals. Shapiro-Wilk test showed the significant deviation from normal distribution in some cases. But ANOVA is less sensitive to the violation of normality assumption (Field et al. 2012). Besides, the sample sizes are large (40, 80, and 130 for cow farms, poultry farms, and pig farms, respectively); the normality assumption was considered not to be a problem according to the central limit

Table 2 Surface water quality classification based on WQI

WQI	Water quality	Color	Possible usage
91–100	Excellent	Blue	Can be used for drinking water supply
76–90	Good	Green	Can be used for drinking water supply after being properly treated
51–75	Marginal	Yellow	Can be used for irrigation and other equivalent purposes
26–50	Bad	Orange	Can be used for transportation and other equivalent purposes
10–25	Heavily polluted	Red	Water is heavily polluted and need to be purified
< 10	Extremely polluted	Brown	Water is extremely polluted and become toxic.

theorem. However, the variances of water quality parameters and WQIs were unequal among farm types based on the results of Levene's test; Welch's ANOVA was thus employed instead of traditional one-way ANOVA. If the statistically significant differences existed among farm types, the post hoc tests (using Games-Howell adjustment procedure) would be applied to find which particular differences between pairs of means are significant.

All data manipulation and statistical analyses were performed in the R environment for statistical computation version 3.5.1 for Macintosh (R Development Core Team 2018).

Results and discussion

Assessment of wastewater, ground water, and surface water by national technical regulations

Wastewater quality assessment

The water quality parameters of effluents from cow farms, poultry farms, and pig farms are shown in Fig. 2. Generally, effluents from cow farms contained more pollutants than pig farms and poultry farms. Cow farms and pig farms have higher mean concentration of BOD_5 (946 ± 1128.1 mg/l and 660.2 ± 400.6 mg/l, respectively), COD (1624.6 ± 2001.9 mg/l and 1107.7 ± 701.6 mg/l, respectively), and TN-N (63.8 ± 62.9 mg/l and 56.7 ± 58.7 mg/l, respectively) compared to poultry farms (317.4 ± 685.1 mg/l, 667.5 ± 1492 mg/l and 29.4 ± 58.2, respectively), and these differences are statistically significant at 5% level of significant. However, the differences in mean concentration of BOD_5, COD, and TN-N between cow farms and pig farms were not statistically significant with the respective p values of 0.27, 0.26, and 0.8.

Pig farms had the highest mean TP-P concentration of 118.7 ± 75.5 mg/l, which was more than 5 times higher than that of cow farms (23.1 ± 20.7 mg/l) and poultry farms (21.8 ± 43.6 mg/l). The difference in mean TP-P of cow farms and poultry farms was not statistically significant (p = 0.97). Wastewater effluent from cow farms represented the highest contamination degree of CF (1.2e+07 ± 5.0e+07 MPN/100ml) which are 8 and 136 times higher compared to poultry farms and pig farms, respectively. However, these differences were not statistically significant (p = 0.42 and 0.32, respectively). On the contrary, the difference between the means of poultry farms (1.5e+06 ± 4.2e+06 MPN/100ml) and pig farms (8.8e+04 ± 7.1e+04 MPN/100ml) was significant (p = 0.008).

All wastewater quality parameters had very high degree of variations, especially in poultry farms with CV being of more or less 200% for all measured variables. The lowest variation was observed in pig farms with only TN-N showing high CV of more than 100%. The CVs of cow farms ranged from 90% (TP-P) to 430% (CF).

Compared with the national technical regulation on the effluent of livestock (QCVN 62), effluents from cow farms, poultry farms, and pig farms in Hanoi showed high degree of non-compliance in all effluent's quality parameters. Particularly, almost all samples of three farm types have CF concentration higher than the permissible limit in QCVN 62 (3900 MPN/100ml). More than 85% of the samples from pig farms and 55% of the samples from cow farms did not meet the requirements of BOD_5, COD, TP-P, and TSS in effluent. Poultry farms had the lowest level of non-compliance; however, 37.5%, 28.7%, 27.5%, and 30% of their samples exceeded the permissible limits for BOD_5, COD, TP-P, and TSS, respectively. TN-N is the parameter having the highest level of compliance with the percentage of samples of cow farms, poultry farms, and pig farms exceeding the permissible limit (117 mg/l) being 15%, 5%, and 22.3%, respectively.

Concerning the magnitude of non-compliance, the highest number of times of exceeding the permissible limits were observed in cow farms for BOD_5 (median of exceeding permissible limits is 8.8 times), TSS (median = 2.4 times), and CF

Table 3 Ground water quality classification based on WQI

WQI	Rating of water quality	Grade
0–25	Excellent water quality	A
26–50	Good water quality	B
51–75	Poor water quality	C
76–100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

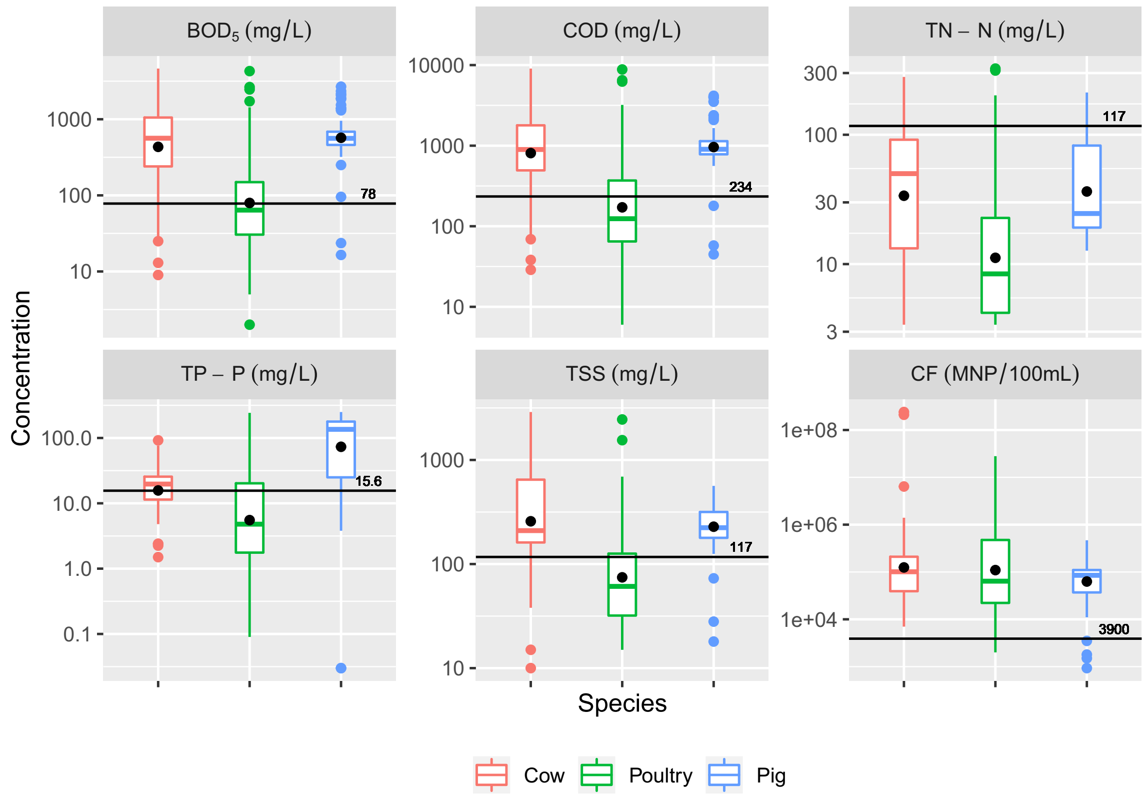

Fig. 2 Wastewater quality of different farm types. Boxplots and black dots represent the distribution and the mean concentration of water quality parameters, respectively. The black lines represent the permissible limits in national technical regulation on effluent of livestock (QCVN 62). Note that TP-P permissible limit was taken from the national technical regulation on the effluent of aquatic product processing industry. The *y*-axes are in logarithm with base 10 scale

(median = 26 times); in poultry farms for COD (median = 6.1 times) and TN-N (median = 2.2); and in pig farms for TP-P (median = 9.2 times).

The low quality of livestock wastewater effluent is popular in Vietnam. Vu (2014) found that the efficiency of biogas in treating swine wastewater was being underestimated. BOD_5 and COD concentrations in effluents were 3 to 5 times higher than the permissible levels, while CF exceeded 4–2000 times compared to the permissible limit. Phung et al. (2009) also found a serious bacterial pollution in livestock wastewater effluent with the levels of CF in smallholder farms and commercial farms being 278 and 630 times higher than the permissible limit.

Ground water quality assessment

The results of ground water analysis are showed in Fig. 3. Generally, the quality of ground water in all farms was almost within the permissible limits for chemical variables in national technical regulation on ground water quality in Vietnam (QCVN 09). The results showed that no sample in all studied farms exceeded the permissible limits for Zn and Cu while only 3 samples of poultry farms and 5 samples of pig farms (3.8% of all samples in these farm types) were found to be polluted by As. Moreover, the median concentrations of As in these samples just exceeded the permissible limits by 1.1–1.2 times. Pb pollution was even less popular with only 2 samples (5%) of cow farms, 2 samples (2.5%) of poultry farms, and 1 sample (0.8%) of pig farms.

Nutrient pollution was also found in collected ground water samples, of which NO_3^--N pollution was less observed (i.e., only 6 samples of poultry) than the NH_4^+-N pollution (i.e., 24 samples from all three farm types). More particularly, 10 samples of cow farms, 13 samples of poultry farms, and only one sample of pig farms have NH_4^+-N concentration higher than the permissible limit (i.e., 1 mg/l according to QCVN 09). However, the differences in mean concentration of NH_4^+-N among 3 farm types were not statistically significant (p-value = 0.13). The ground water pollution caused by NH_4^+-N has also been found by Ho et al. (2013) with NH_4^+-N concentration in ground water samples in pig farms of Hungyen province being 3 to 11 times higher than the permissible limit.

Ground water in pig farms was more polluted by COD than in cow farms and poultry farms. Particularly, mean concentration of COD in ground water of pig farms (3 ± 1.3 mg/l) was statistically significantly higher than in cow farms (0.7 ± 0.5 mg/l, p-values = 0) and poultry farms (1.3 ± 1.8 mg/l, p-value = 7.5E-11). More than 19% of ground water samples in pig

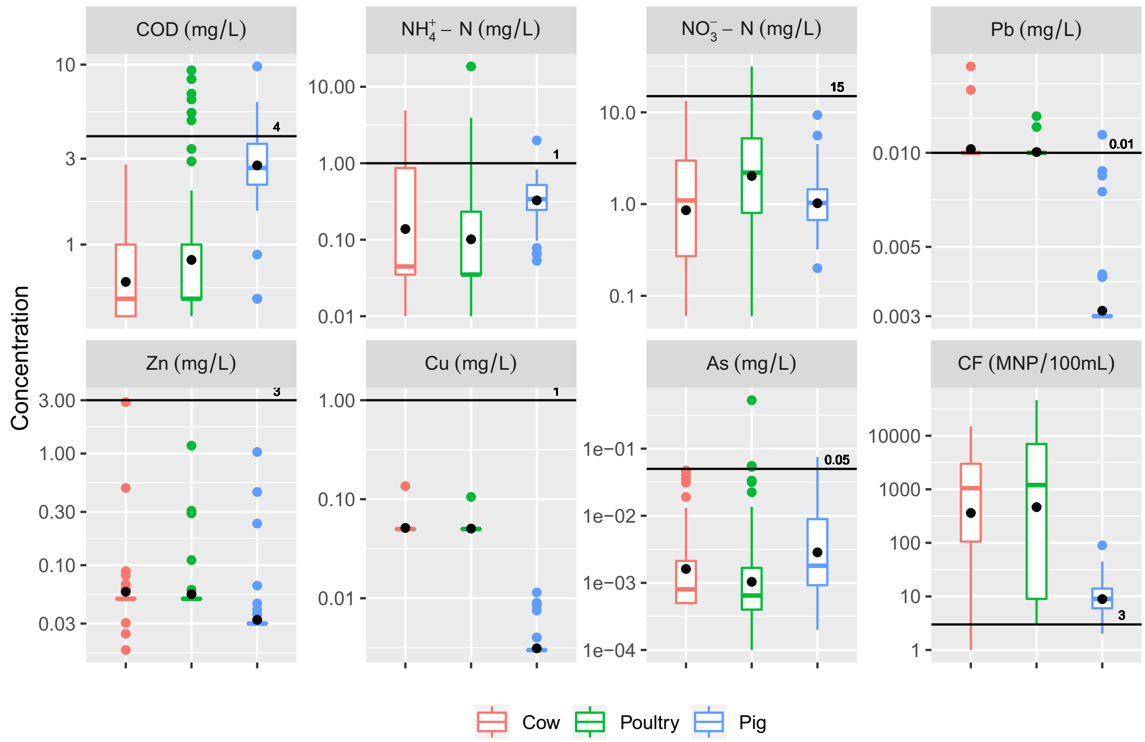

Fig. 3 Ground water quality at different farm types. Boxplots and black dots represent the distribution and the mean concentration of ground water quality parameters, respectively. The black lines represent the permissible limits in national technical regulation on the quality of groundwater (QCVN 09). The *y*-axes are in logarithm with base 10 scale

farms having COD did not meet the maximum allowable limit of 4 mg/l. This figure of poultry farms was 8.8% while COD in all samples of cow farms were lower than permissible limits.

Remarkably, ground water in the studied livestock farms were heavily polluted by CF. The proportion of samples exceeding permissible limit (3 MPN/100 ml) in cow farms, poultry farms, and pig farms were 85%, 86.2%, and 93.1%, respectively. However, the severity of CF pollution was more pronounced in cow farms and poultry farms and to lesser extent in pig farms. The mean concentration of CF in cow farms and poultry farms was 2375±3430 and 5011±8452 MPN/100ml, respectively which were statistically significantly higher than that of pig farms (11.3±10 MPN/100ml) with the respective *p*-values of 2.7E-4 and 3.2E-6. Besides, the medians of concentration of CF of samples exceeding permissible limit of cow farms and poultry farms were 667 times higher than the permissible limit, whereas this value in pig farms was 3 times.

Surface water quality assessment

The results of surface water quality analysis are depicted in Fig. 4. Surface water near cow farms had the higher mean concentration of BOD_5 (37.8 ± 57.6 mg/l), COD (85.3 ± 102.4 mg/l), NH_4^+-N (6.7 ± 16.6 mg/l), and TSS (76.5 ± 219.8 mg/l) compared to those of poultry farms and pig farms. However, the differences in mean concentration of BOD_5 and TSS among all farm types were not significant (*p*-values = 0.38 and 0.12, respectively). The differences in mean concentration of NH_4^+-N and COD were only found to be significant between pig farms and poultry farms (*p*-values of 0006 and 0.049, respectively). More specifically, mean concentration of NH_4^+-N in surface water surrounding pig farms (3.3 ± 3.5 mg/l) was two times higher than that of poultry farms (1.6 ± 2.8 mg/l).

Surface water near poultry farms exhibited the highest mean concentration of NO_3^--N (3.2 ± 3.4 mg/l), which was significantly higher than that of cow farms (1.8 ± 1.8 mg/l, *p*-value = 0.016) and pig farms (1.8 ± 2.1 mg/l, *p*-value = 0.003). Concerning PO_4^{3-}-P, the mean concentration in surface water surrounding pig farms (2.3 ± 3.5 mg/l) was 1.6 times higher than that of poultry farms (1.4 ± 2.1 mg/l); and the difference was found to be significant (*p*-value = 0.04). However, the difference in mean concentration of PO_4^{3-}—P was not significantly different between samples of pig farms and cow farms (2.1 ± 3.6 mg/l, *p*-value = 0.95). The variations of pollutant concentrations were the most obvious in surface water near cow farms with CV ranging from 3.9% (pH) up to 287% (TSS).

The quality of surface water surrounding livestock farms was assessed by comparing to the national technical regulation on quality of surface water in Vietnam (QCVN 08, category B1). Almost all surface water samples had pH and NO_3^--N

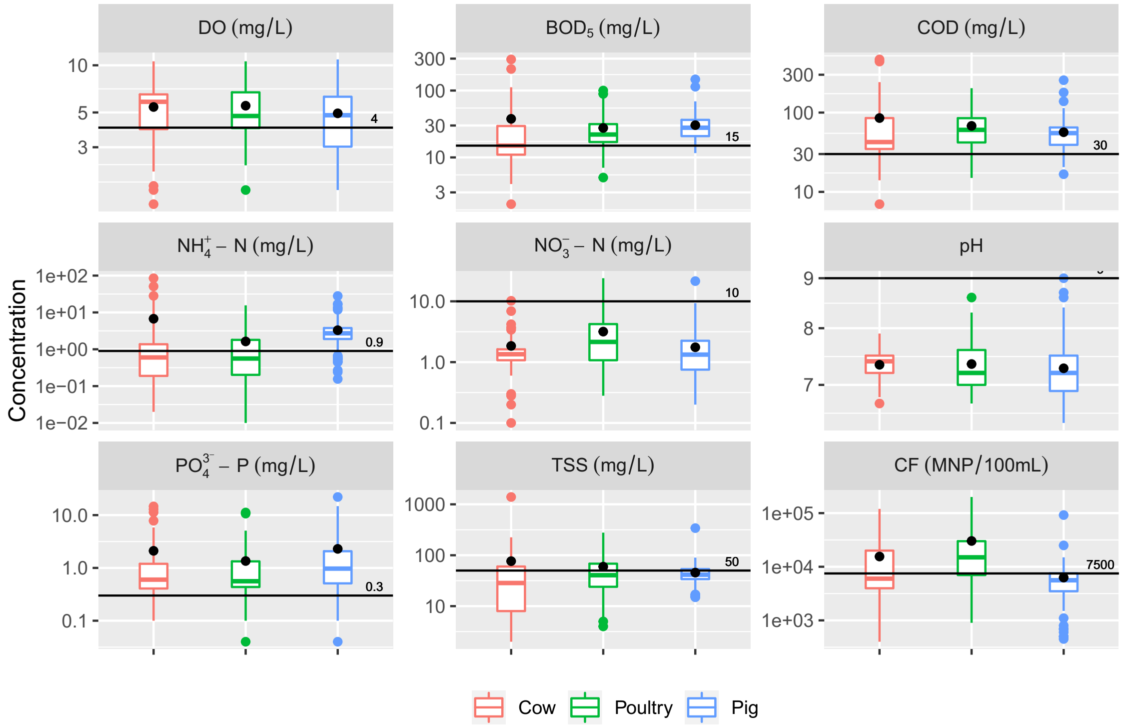

Fig. 4 Surface water quality at different farm types. Boxplots and black dots represent the distribution and the mean concentration of surface water quality parameters, respectively. The solid lines represent the limits according to the national technical regulation on surface water quality in Vietnam (QCVN 08. category B1). The *y*-axes are in logarithm with base 10 scale

concentration falling within allowable limits in QCVN 08 (category B1). DO concentration in 25% of surface water samples near cow farms and poultry farms felt bellow minimal requirement of 4 mg/l. This figure for surface water sample near pig farms was nearly 40%. Surface water near livestock farms was more polluted by organic matters and PO_4^{3-}-P with more than 80% of all samples exceeding the desirable limits of BOD_5, COD, and PO_4^{3-}-P in QCVN 08 (category B1), except for BOD_5 in surface water near cow farms (47.5%). The median concentrations of these pollutants were about 2 times higher than desirable limits in QCVN 08 (category B1).

NH_4^+-N was also an important pollutant in surface water. Surface water near poultry farms and pig farms had 43.8% and 83.1% of samples exceeding permissible limit of NH_4^+-N (0.9 mg/l), whereas this proportion in surface water near cow farms was 30%. However, the degree of pollution by NH_4^+-N was more pronounced in surface water near cow farms with median concentration in samples exceeding permissible limit of NH_4^+-N which was 17.1 mg/l.

Ho et al. (2013) found the pollution caused by NH_4^+-N, BOD_5, and COD in receiving surface water bodies near pig farms in Hungyen province even more pronounced, exceeding the permissible limit up to 106, 91, and 58 times, respectively.

Total coliform (CF) was another polluting factor of surface water near livestock farms. Surface water near poultry farms was more polluted by CF compared to surface water near pig farms and cow farms. It had highest proportion (nearly 90%) of samples exceeding desirable limit of CF (7500 MPN/100 ml) with median concentration of 23,250 MPN/100 ml.

Assessment of ground water and surface water by water quality index

WQI of groundwater

The resulting WQIs for groundwater samples varied among different farm types (Fig. 5). Large variations of WQIs were seen for groundwater samples of poultry farms (CV = 142.1%) and cow farms (CV = 102.2%). More particularly, WQI varied from 81.7 to 4254.7 (mean = 538.6) for the former and from 81.7 to 1436.8 (mean = 301.8) for the latter. In pig farms, WQIs of groundwater samples were more stable around the mean of 30 (range: 25.2–94.5 and CV of 33.5%). Welch's ANOVA test revealed the significant difference in mean WQI among 3 farms types (p-value = 9.5E-11). Also, the post hoc test showed the differences between any 2 farm types were statistically significant (p-value < 0.05).

Based on WQI, groundwater can be classified into 5 categories, i.e., excellent, good, poor, very poor, and unsuitable for drinking purpose. The water quality classification structure was similar in cow farms and poultry farms. About 70% of total groundwater samples in these two farm types were categorized as unsuitable for drinking water supply purpose, and the rest were classified as very poor condition. This indicated

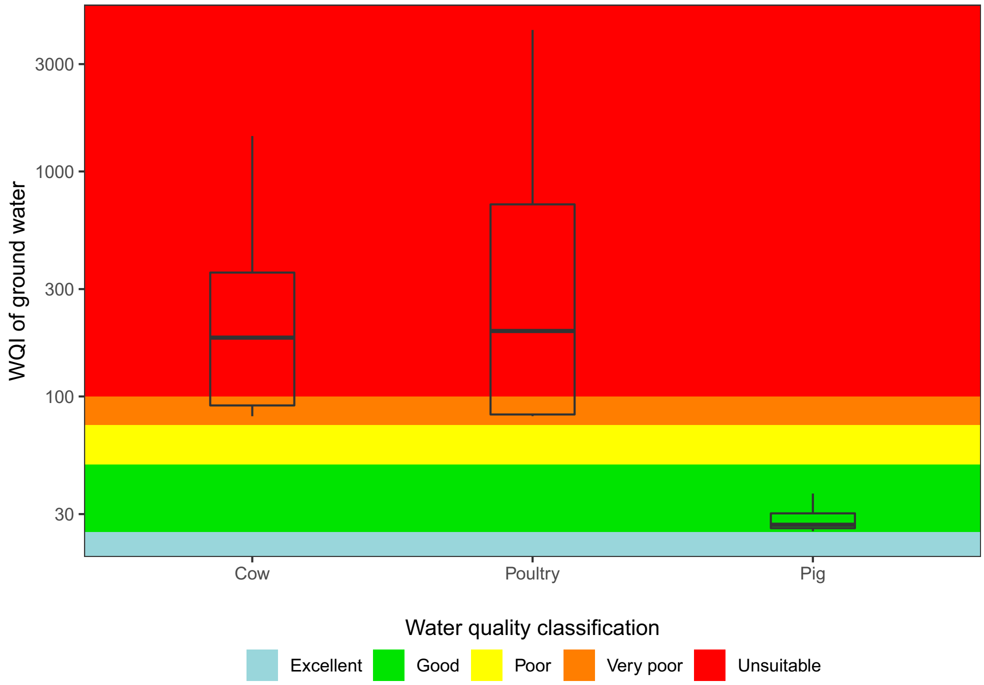

Fig. 5 Boxplots represent the distribution of WQI of ground water samples at different farm types. The *y*-axis is in logarithm with base 10 scale

that these groundwater sources were heavily polluted. On the contrary, groundwater in pig farms was still in good quality (96.9%). Only 0.77 and 2.31% of the total water samples in pig farms were classified as being poor and very poor quality.

Based on the analysis of effective weights, it is clear that Pb and coliform were the most determining factors for ground water quality of cow farms and poultry farms, whereas As and Pb were more important for groundwater quality in pig farms.

WQI of surface water

The WQIs calculated for surface water samples at different farm types are presented in Fig. 6. Welch's ANOVA test showed there were statistically significant differences in mean WQI among 3 farms types (p-value = 8.6E-7). Cow farms have highest mean WQI of 50.3 ± 20.8, followed by pig farms (49.9 ± 12) and poultry farms (37.5 ± 16.2). However, post hoc test revealed that the difference in mean WQI between cow farms and pig farms was not statistically significant (p-value = 0.1). In general, the overall quality of surface water samples near poultry farms was worst among three farm types. The proportion of water samples near poultry farms being classified as very bad, bad, and marginal was 5%, 71.25%, and 21.25%, respectively. More than 53% of surface water samples near pig farms belong to marginal quality class (highest proportion among three farm types), whereas this proportion of water samples near cow farm is 35%. There were only total of 2 surface water samples which were collected near pig farms considered as extremely polluted. The proportion of surface water samples in good quality was low in all farm types (12.5%, 2.5%, and 0.8% for cow farms, poultry farms, and pig farms, respectively). Generally, surface water quality near livestock farms has been considerably degraded.

Because there was lack of data on water temperature, we assumed that the water temperature equals to the average air temperature during the sampling period (T=30°C). We conducted a sensitivity analysis to examine the impact of this assumption on the obtained surface water WQI by considering a variation range of 20% of water temperature. The results showed that WQI calculation was quite robust with the changes in temperature. The mean coefficient of variation of all 250 water samples was 1.17% with the range of 0–3.35%. Moreover, variation in temperature only resulted in the changes in water quality class in some iterations of 20 water samples.

Livestock's waste as a significant potential source of water pollution

Livestock production produces a large amount of manure with the volume of manure per animal (l/day) ranging from 5.4 to 45.3, 5.1 to 11.3, and 0.08 to 0.14 for cattle, pig, and chickens, respectively (Ogbuewu et al. 2012). Also, cattle and swine production discharges a large amount of wastewater of about 60 and 10l/head/day, respectively (Villamar et al. 2018). Livestock wastes are considered as the greatest agricultural source of water pollution (Dopelt et al. 2019). For example, the US Department of Agriculture stated that animal parts and poultry manure are major sources of water pollution (Ilea 2009). Animal waste contains high amount of nutrients (i.e.,

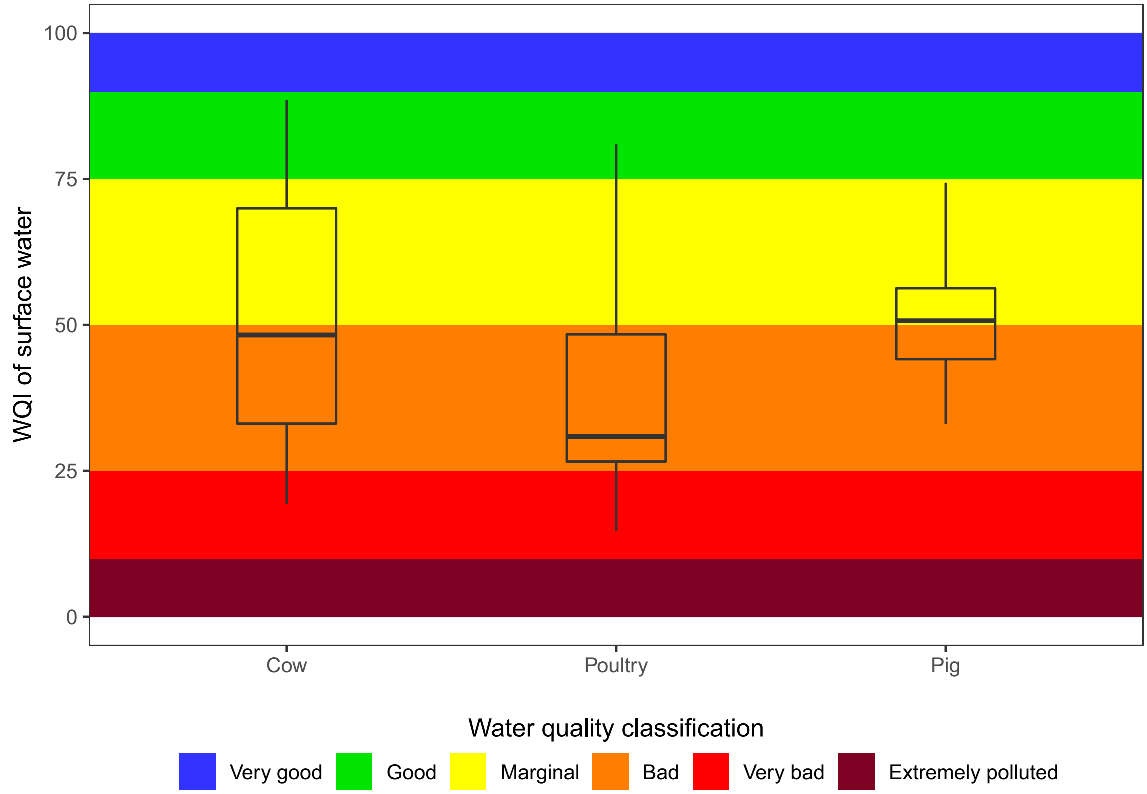

Fig. 6 Boxplots represent the distribution of WQI of surface water samples at different farm types

N and P), with the average concentration varying with livestock and farm types. The respective nitrogen content in cow manure, chicken litter, and solid pig manure is of 7.7±5.7%, 29±8.6%, and 13.9±14%. These figures of phosphorus (expressed as P_2O_5) are of 4.3±5.2%, 25.6±8.0%, and 13.6 ±13.5%, respectively (Velthof et al. 2015). On the other hand, the raw livestock's wastewater contains high content of nutrients, organic matters, and also pathogenic microorganisms. COD, for instance, varied from 24,000 to 65,000 mg/l in swine farms and from 2600 to 41,000 mg/l in cattle farms (Villamar et al. 2013, 2018). They hence might greatly contribute to water pollution if not properly treated. The results from our study indicated that wastewater from livestock farms in Vietnam has not been treated efficiently. The effluent was not qualified according to QCVN 62 with high proportion of samples exceeding the permissible limits. Generally, the effluent from poultry farms showed better quality compared to those from cow farms and pig farms. This can be explained by the fact that poultry litters were usually collected separately with only small amount going into the wastewater treatment systems. Moreover, large fraction of cow manure and pig manure was collected as slurry and put into the wastewater treatment systems, making these systems overloaded. Wastewater in pig farms and cow farms was most treated by biogas systems of which many systems were not properly maintained and thus being degraded. These seem to be the reasons for a high concentration of organic matters and nutrients in the effluent of many pig farms and cow farms. Concentration of TP-P in pig farms' effluent was much higher compared to those of cow farms. This might be due to higher concentration of phosphorus in pig manure as mentioned above.

High contamination levels of CF in wastewater from cow farms and poultry farms were likely to result in the CF contamination in ground water and therefore poor overall ground water quality in these farms. Most of ground water samples in cow farms and poultry farms were classified as unsuitable for drinking purpose based on WQI, although most of chemical water quality parameters felt within the permissible limits of QCVN 09. Therefore, it is necessary to treat groundwater properly before using it for raising animals and human drinking to prevent the diseases-related microbial contamination. The microorganism contamination of ground water from livestock's waste has been found elsewhere (e.g., Hubbard et al. 2020). Application of WQI is a good way to give a signal to pay attention to the overall water quality when few of water quality parameters are bad and others are not.

Regarding the overall surface water quality, WQI indicated that receiving water bodies near poultry farms exhibited the worst quality, although the amount of wastewater generated and pollutant concentration in their effluents was much lower compared to pig farms and cow farms. This can be explained by the fact that poultry farms were usually located in the proximity of the populated residential areas where the domestic wastewater and livestock wastewater were discharged together into the common sewer systems before going into the receiving water bodies. As such, poultry wastewater was not the only pollution source of receiving surface water bodies. As a result, there should be a plan to move these poultry farms outside of residential areas.

Limitations

There is an increasing concern about the presence of emerging pollutants, "which are currently not included in routine environmental monitoring programs and which may be candidates for future legislation due to their adverse effects and/or persistency" (Bunke et al. 2019), in water environment (Bottoni et al. 2010). Livestock production is considered as an important source of these pollutants due to the application of veterinary medicines (e.g., antibiotics, artificial growth hormones) in livestock farms (Geissen et al. 2015; Kaczala and Blum 2016; Mateo-Sagasta et al. 2018). Once leaching from animal waste storage and livestock farms' wastewater effluent, these pollutants may enter and contaminate water. However, emerging pollutants are currently not included in assessing the quality of effluent from livestock farms in Vietnam. We, therefore, should pay more attention on the occurrence of these emerging pollutants and their effects on human health and aquatic ecosystem quality in future research when assessing the impacts of livestock production on water quality.

The current data does not allow inferring directly relationship between farms' activities and ground water quality. Livestock waste can pose serious threats to groundwater via several pathways, such as surface runoff from farm building, improper discharge, leaking from storage facility, and excessive land application of waste (Sahoo et al. 2016). However, the extent and source of contamination are often harder to poinpoint in ground water than surface water contamination (Harter et al. 2014). To assess the connection of ground water quality with the activity of livestock farms, it is necessary to design a proper system of monitoring wells. The number of monitoring wells and samples for each site is largely dependent on local condition. Typically, the minimum required number of monitoring wells to assess the contamination of groundwater caused by livestock farms in USA, Canada, and Australia ranges from 3 to 4 in which one well from up-gradient and 2 to 3 wells from down-gradient (Sahoo et al. 2016). As such, the future monitoring campaign should be focused on designing more proper monitoring wells to reveal the direct connection between farm activities and ground water quality.

Our study's results give only a snapshot of water quality status within and near livestock farms in Vietnam. A regular long-term monitoring program should be implemented in the future to better assess the impacts of livestock production on water quality as well as the efficiency of livestock's waste treatment efficiency.

Conclusion

Water pollution within and near livestock farms was for the first time comprehensively assessed in Vietnam. The results indicated that effluent from livestock farms in Vietnam was heavily polluted by organic matters (expressed as BOD_5, COD) and to lesser extend by nutrients (i.e., TN-N and TP-P). Especially, it was severely contaminated with microorganisms (expressed as coliform—CF) with almost all of 250 wastewater samples were observed to have CF exceeding the permissible limit in the national technical regulation on livestock's effluent. These results indicated that the existing wastewater treatment facilities were not adequate to treat high strength wastewaters discharged from pig farms, cow farms, and poultry farms. The inefficiency of wastewater treatment in livestock farms was likely to affect surface and ground water quality. Surface water nearby the livestock farms was most polluted by organic matters, PO_4^{3-}-P and CF. Overall quality of surface water near poultry farms was worst among all farm types, which might be resulted from combined impacts of livestock wastewater and domestic wastewater from nearby densely populated residential areas. Generally, ground water in all farm types was in good condition in terms of chemical water quality parameters; however, high degree of CF contamination was observed in cow farms and poultry farms. This might lead to ground water in these farms being classified as unsuitable for drinking water supply purpose. Future researches should pay more attention on the occurrence and effects of emerging pollutants in water environment resulting from livestock farms.

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conceptualization, methodology, formal analysis, visualization, writing original draft and editing, supervision.

Declarations

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