SURFACE WATER POLLUTION AND PROPOSED SOLUTIONS FOR QUALITY IMPROVEMENT IN KIM XA COMMUNE, VINH TUONG DISTRICT, VINH PHUC, VIETNAM

Ha Thi Nguyen*, Khai Manh Nguyen, Phuong Minh Nguyen, Tú Anh Cai, Tin Trong Nguyen, Dat Nguyen, Duong Khanh Thi Pham, Ly Huong Vu, Anh Quang Tran, Trang Quynh Le, Duong Thuy Nguyen, Nhat Minh Duong

Faculty of Environmental Sciences, University of Science, Vietnam National University, Hanoi
334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam
**Corresponding author: nguyenthiha@hus.edu.vn*

ABSTRACT

The study investigated the current surface water pollution status in Kim Xa Commune, Vinh Tuong District, Vinh Phuc Province, in Northern Vietnam. Water samples were collected from Phan River, fish farms/ponds, and a pig farm's effluent in Kim Xa Commune and analyzed for water quality parameters, including chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). Results showed that the Phan River water met the national water quality standards (Regulation QCVN 08:2015/BTNMT). However, the COD and TSS concentrations of the pond water and the piggery effluent exceeded their maximum permitted levels (QCVN 08:2015/BTNMT and QCVN 62:2016/BTNMT). Both had the highest COD of 145 and 192 mg/L, respectively. Moreover, the effluent's TSS was 2.05 times higher than the national standard (QCVN 62:2016/BTNMT, column B). A 500 m^2 floating treatment wetland system planted with water hyacinth has been proposed for improving the quality of the piggery effluent discharged to recipient drainage to meet the standards regulated in QCVN 08:2015/BTNMT for surface water.

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1. INTRODUCTION

Together with rapid industrialization and capitalization growth, environmental pollution issues have become increasingly serious. Kim Xa Commune in Vinh Tuong District, Vinh Phuc Province, Northern Vietnam, is the leading development site for crop and livestock production in the province. As the region continues to grow fast, environmental pollution has become increasingly problematic and thus raised concerns due to wastewater from production and settlement areas. Phan River traverses through Kim Xa Commune, making it the most affected by industrial and domestic wastewater.

Most piggeries in Vietnam are small and medium-sized and use a considerable amount of water, about 30–49 L/pig per day. Of which, about 30–40 L/pig per day is spent on barn sanitation. The piggery wastewater is composed of widely diverse potent contaminants, including 2,500–12,120 mg/L of COD, 185–4,539 mg/L of TN, 28–831 mg/L of TP, 190–5,830 mg/L of SS, and $4x10^4$–10^8 MPN/100 mL of coliforms (Canh, 2015]. Figure 1 shows nitrite concentrations (mg/L) of Phan River water during 2016–2020 (Vinh Phuc Donre, 2020) and Figure 2 shows ammonium concentrations (mg/L) of Phan River water during 2016–2020 (Vinh Phuc DONRE, 2020).

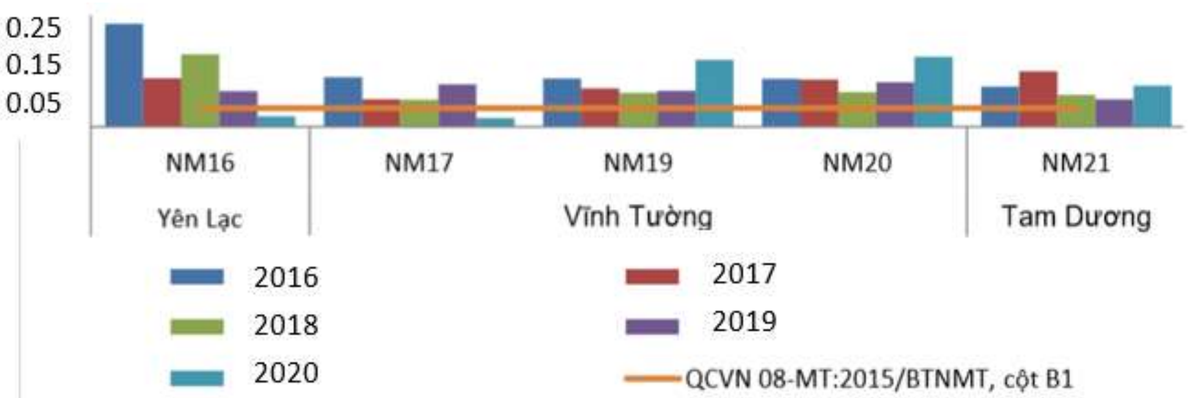

Figure 1. Nitrite concentrations (mg/L) of Phan River water during 2016–2020 (Vinh Phuc DONRE, 2020)

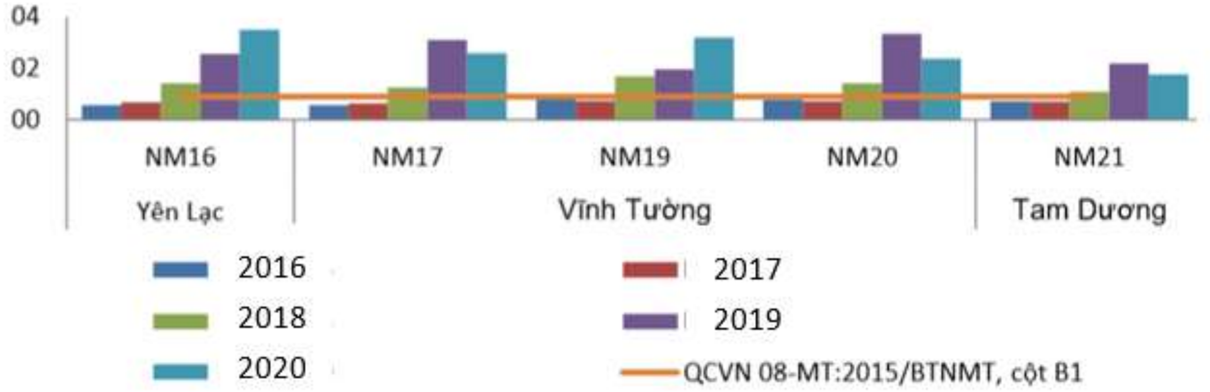

Figure 2. Ammonium concentrations (mg/L) of Phan River water during 2016–2020 [Vinh Phuc DONRE, 2020]

According to the current surface water assessment by the Vinh Phuc Department of Natural Resources and Environment [2020], Phan River's ammonium and nitrite contents have exceeded QCVN 08:2008/BTNMT column B1 and show a gradual upward trend during 2016–2020 (see Figures 1 and 2). There is no substantial difference between their concentrations in the upper and lower courses. However, the PO_4^{3-} is approximately QCVN (0.28 mg/L). Despite the efforts to lower COD and BOD_5 to below their maximum permissible levels in the 2016–2020 period, observations at six sampling sites during four water quality monitoring campaigns in 2021 found that at least COD exceeded the standard. They also showed that two other parameters were present in excessive amounts, with the highest NO_2^- reaching 0.088 mg/L and NH_4^+ 4.7 mg/L or 5.22 times higher than the permitted standard.

Figure 3 shows the Phan River channel flowing through Kim Xa Commune. Kim Xa commune is a locality with exceptional agricultural and industrial activities. Local government officials regularly encourage and advise local farmers on crop farming, livestock farming, irrigation, and disaster prevention practices and perform routine monitoring. With this assistance, Kim Xa remains the leading commune in agricultural and industrial production activities in the province.

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Figure 3. Phan River flows through the Kim Xa Commune, Vinh Tuong Province, Vietnam

The study area currently has a wastewater treatment system for piggery effluent, established as part of the Protocol Project developed and implemented by the VNU University of Sciences (T. H. Nguyen, 2019). The pilot-scale moving bed biofilm reactor (MBBR), designed with a capacity of 10 m^3/day, is a bioremediation process that combines a conventional activated sludge process and biofilm media. The MBBR system consists of an activated sludge aeration system where sludge is collected in resin carriers. These carriers have a large internal surface for optimal contact with water, air, and bacteria. Bacteria in the activated sludge grow on the inner surface of the carrier and decompose the organic matter in the piggery effluent. The innovative upflow anaerobic sludge blanket (UASB) model keeps the activated sludge carriers in motion. When the bacteria continue to multiply, the excess sludge will be separated from the carrier and discharged together with the treated barn wastewater into the environment (T. H. Nguyen et al., 2021).

MATERIALS AND METHOD

Materials

Water samples were collected from Phan River (surface water), fish ponds, and the effluent of a pig farm drainage, Tran Van Tinh, in the Kim Xa Commune, Vinh Tuong District, Vinh Phuc Province, according to the Vietnamese water quality standards TCVN 6663-6:2018. Table 1 shows the sampling locations. Figure 4 shows surface water sampling sites.

Table 1. Water sampling sites in the study area

Sample	Location	Characteristics	Sampling Depth (cm)
M1.1	Phan River	Midstream	20
M1.2	21°18'52.4"N, 105°29'54.0"E	Close to the shore	
M2.1	Fish pond	Middle pond	20
M2.2	21°18'51.9"N, 105°29'53.9"E	Close to the shore	
M3.1	Pig farm drainage	Midstream	15
M3.2	21°19'07.6"N, 105°30'42.0"E	Close to the shore	

Figure 4. Surface water sampling sites in Phan river (a) and fish pond (b)

One household-scale livestock production generates wastewater directly from pig farms and cleaning, on average, five large pig pens to house 600–650 pigs. Piggery wastewater may vary in composition and characteristics over time, depending on pig growth.

Methods

Water samples were tested for typical water quality parameters, including chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). COD analysis used potassium dichromate per SMEWW 5220C:2012, TSS per SMEWW 2540D:2012, TN per SMEWW 4500N C:2012, and TP per SMEWW 4500P B&E:2012 (APHA, 2012).

Removal efficiency (%) of the constructed wetlands (CWs) was calculated using the difference in concentration (mg/L) between the inlet and outlet divided by the inlet concentration (mg/L) (Eq. 1). The hydraulic loading rate (m^2/day) was calculated as the percentage of the ratio of inlet flow rate to the CW unit area (m^2) (Eq. 2). The loading

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rate (g/m^2.day) was calculated by multiplying the hydraulic loading rate by the inflow concentration (mg/L) (Eq. 3). The removal rate (g/m^2.day) was defined as the hydraulic loading rate (m/day) multiplied by the difference in concentration (mg/L) between the inlet and outlet (Eq. 4) (Anh et al., 2020).

$$Removal\ efficiency\ (\%) = \frac{Inflow\ con. - Outflow\ conc.}{Inflow\ conc.} \quad (1)$$

$$Hydraulic\ loading\ rate\ (m^2/day) = \frac{Inlet\ flow\ rate.}{Inflow\ conc.} \quad (2)$$

$$Loading\ rate\ (g/m^2.day) = Hydraulic\ loading\ rate\ \times\ Inflow\ conc. \quad (3)$$

$$Removal\ rate\ (g/m^2.day) = Hydraulic\ loading\ rate\ \times\ (Inflow\ conc. - Outflow\ conc.) \quad (4)$$

RESULTS AND DISCUSSION

Assessment of current water pollution status

Table 2 summarizes the analysis results of the water samples in the study area. It shows that the Phan River met the national water quality standards for surface water (Regulation QCVN 08:2015/BTNMT); however, the COD and TSS concentrations of the pond water used in fish farming and the piggery effluent exceeded their maximum allowable levels (red-colored figures). The highest COD value of the pond water and the piggery effluent was 145 and 192 mg/L, respectively. Moreover, the TSS concentration in the piggery effluent was about 6.16 and 2.05 times higher than the national standards QCVN 62:2016/BTNMT columns A and B, respectively.

Table 2. Characteristics of wastewater samples in the study area

Parameters (mg/L)	M1.1	M1.2	M2.1	M2.2	M3.1	M3.2	QCVN 08:2015/ *		QCVN 62:2016/ **	
							B1	B2	A	B
Total COD	19	25	136	145	178	192	30	50	100	300
Total nitrogen	0.29	0.23	0.73	0.68	4.4	4.1	-	-	50	150
Total phosphorus	3.6	5.1	6.9	7.8	14.4	16.3	-	-	-	-
TSS	14	17	106	97	304	312	50	100	50	150

Note: - : data not available, *) QCVN 08:2015/BTNMT: National Technical Regulation on surface water quality for irrigation or other uses with similar water quality requirements (column B1) and waterway transport or other uses with low water quality requirements (column B2), **) QCVN 62:2016/BTNMT: National Technical

Regulation on the effluent of livestock that can (column A) or cannot be reused for domestic purposes (column B).

Solution proposed for improving water quality

A solution for improving the piggery effluent quality has been proposed. Among various water quality improvement methods, constructed wetlands (CWs) have been the most increasingly applied due to their low cost, ease of operation, and reliance on the natural function of vegetation, making them environmentally friendly (Vymazal & Kröpfelová, 2008; Wu, Kuschk, Brix, Vymazal, & Dong, 2014).

1. Rationale for selecting floating treatment wetlands

The channel surrounding Tinh's Pig Farm is 1.0 km long, 4.0 m wide, and 1.5 m deep. With these parameters, the channel can be used for floating treatment wetlands. Floating treatment wetlands (FTWs) or islands are small artificial platforms that allow the roots of aquatic emergent plants to spread through the floating islands and down into the water, creating dense columns of roots with lots of surface area. This way, FTWs can utilize the natural ability of emergent aquatic plants (e.g., *Eichhornia crassipes*) and degrade contaminants through biological processes known as bioremediation. The essential characteristics of wastewater from livestock farms, especially piggery, are organic contents and nutrients expressed in parameters such as COD, BOD_5, TN, TP, and suspended solids (Boursier, Béline, & Paul, 2005). These are easily decomposed components, causing stench, generating toxic gases, and reducing the amount of dissolved oxygen in the water. Thus, treating them improperly before being discharged into the receiving water can lead to environmental pollution. When the floating wetlands are operated, the plants take up nutrients and contaminants while the plant roots and floating island material provide extensive surface area for microbes to grow—forming a slimy layer of biofilm. The biofilm is where the majority of nutrients are stored and degradation occurs in an FTW system. The shelter the floating mat provides also allows sediment and elements to settle by reducing turbulence and mixing by wind and waves. The unique ecosystem that develops creates the potential to capture nutrients and transform common pollutants that would otherwise plague and harm the lake into harmless byproducts. Thus, floating wetlands, where both plants and microbes absorb nutrients like phosphorus and nitrogen, are very

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suitable for treating typical pollutants in Tinh's livestock wastewater.

2. Rationale for selecting water hyacinth (Eichhornia crassipes)

Eichhornia crassipes is one of the most common aquatic plants in tropical and subtropical regions worldwide, especially in Vietnam. It is easy to find them in large quantities in freshwaters such as lakes, ponds, or reservoirs. For this reason, *E. crassipes* was chosen in order to save cost and growth time. Treatment systems with *E. crassipes* have been successfully applied in the tropics and subtropics. The primary reason for its limited use in regions with temperate or colder climates is that frost can severely damage water hyacinth and the growth rate is substantially reduced at temperatures below 10^{o}C (Vymazal & Kröpfelová, 2008). Secondly, *E. crassipes'* reproduction and growth rate is relatively fast (Jayaweera et al., 2008), which gives a significant advantage to wastewater treatment (Vymazal & Kröpfelová, 2008). Floating treatment wetlands with water hyacinths are usually remarkably effective for reducing or removing organic pollutants, suspended solids, and nutrients (Vymazal & Kröpfelová, 2008). The plant's capacity to treat organic pollutants has also been well documented (Lima et al., 2018; Lu, Fu, & Yin, 2008; Madikizela, 2021).

There is a number of studies relating to wastewater and surface treatment with water hyacinth [Gupta *et al.*, 2012 and Gupta *et al.*, 2015]. In Gupta et al. (2015), an experiment was prepared and carried out in Dhanbad, Jharkhand (India), for two coal mines, one municipal wastewater, and one tap water using four floating aquatic plants: algae, vetiver grass, hydrilla, and water hyacinth that had been grown in the tub at laboratory scale. These systems were observed after 0, 5, 10, and 15 days. The four types of water treated with water hyacinth were analyzed for pH, sulfate, iron, and nitrate contents. After 15 days, sulfate, iron, and nitrate removal efficiency reached 50–63, 20–40, and 33–88 %, respectively. In addition, this research emphasized the need for a thorough cost-benefit analysis to assess the economic value of long-term solutions and zero-waste management. In Lissy & Madhu (2011), water hyacinth has been used to stabilize temperature, prevent stratification, and promote mixing within the water column in a lagoon-scale experimental study. Based on their findings, water hyacinth can adjust the water pH to neutral, and a 40% reduction in TDS can be achieved after 20 days. According to Lindsey & Hirt (1999), after being used, water hyacinth can be utilized as food or fodder because the leaves contain high protein and vitamin A.

However, it is strongly advised not to re-use the plant if it has been planted to remove heavy metals and harmful chemicals so as to avoid potential health and environmental risks via the food chain. In this case, it can be added in anaerobic digestion composting to produce methane, fermented with sugars into alcohol, and used as green fertilizer, compost, and ash in recovering degraded soils after harvesting. In addition, these practices can assist in reducing wastewater treatment costs.

3. Constructed wetland's dimension based on contaminant removal rates

According to inflow concentration and the regulation QCVN 62:2016/BTNMT, the surface area of the channel was calculated in Eq. 5.

$$S_{Channel} = Length \times Width = 1{,}000 \times 4 = 4{,}000\ m^2 \qquad (5)$$

To meet the standard of Column A livestock effluent (QCVN 62-MT:2016/BTNMT), the surface area was calculated based on the TSS removal rate, which is 53 kg/ha.day or 5.3 g/m^2.day based on 17 pilot-scale constructed wetlands with water hyacinth systems (Vymazal & Kröpfelová, 2008). The TSS removal rate was inputted into the Equation (6) to calculate the hydraulic loading rate (HLR)

$$Hydraulic\ loading\ rate\ (HLR) = \frac{Removal\ rate}{Inflow\ conc. - Outflow\ conc.} = \frac{5.3}{308-50} = 0.0205\ m/day \qquad (6)$$

The average TSS inflow concentration was 308 mg/L or 308 $g/m^{3,}$ and the outflow concentration was equal to the TSS standard for Column A livestock effluent per the regulation QCVN 62-MT:2016/BTNMT, 50 mg/L or 50 g/m^3. The calculated HLR (0.0205 m/day) is similar to the HLR in previous studies that used CWs with water hyacinth: 0.20 to 0.65 m/day. Based on the inlet flow rate and HLR, the area of the CW units was calculated in Equation (7).

$$S_{CW} = \frac{Inlet\ flow\ rate}{Hydraulic\ loading\ rate\ (HLR)} = \frac{10}{0.0205} = \mathbf{487.80\ m^2} \qquad (7)$$

The CW area needed to meet the TSS standard for Column A (domestic supply water) per regulation QCVN 62-MT:2016/BTNMT is **487.80 m^2**. Because it is smaller than the surface area of the channel, 4,000 m^2, the floating treatment wetlands using the water hyacinth method can be used in the study area to remove TSS

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and produce wastewater reusable for domestic purposes following QCVN 62-MT:2016/BTNMT (Column A). Besides, the treatment wetland can also lower COD at a rate of 1.7425 g/m^2.day, as shown in Equation (8).

$$Removal\ rate = HLR \times (Inflow\ conc. - Outflow\ conc.) = 0.0205 \times (185 - 100) = 1.7425\ g/m^2.day$$

Based on the above calculations, treating Tinh's livestock wastewater using CWs planted with water hyacinths to meet the standards in QCVN 62-MT:2016/BTNMT (Columns A and B) is feasible. However, to improve the channel effluent quality to be reusable for domestic purposes, a treatment system design with an area of 500 m^2 is proposed. In addition, the mat in which the plants grow is typically 16.5 m x 3.0 m x 0.2 m (LxWxH) as seen in Figure 5. Therefore, the area (length x width) of a single mat is 49.5 m^2 (16.5 m x 3 m). In a single season, ten plants can completely cover 0.4 ha of a natural freshwater surface (Vymazal & Kröpfelová, 2008). It is suggested to grow 8 plants/m^2. Thus, the number of water hyacinths in each mat is 396, based on this calculation: 8 plants/m^2 x 49.5 m^2 = 396 plants.

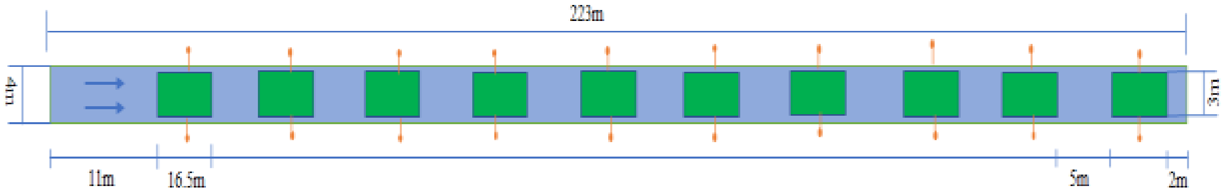

Figure 5. Floating treatment wetlands using water hyacinth model

Livestock wastewater in the study area is contaminated with TSS and COD, and a floating treatment wetland using water hyacinth is highly recommended to produce higher-quality effluent. From data processing, it can be inferred that a treatment system with an area of 500 m^2 is preferable to achieve the most favorable outcome.

CONCLUSIONS

The Phan River channel that flows through the Kim Xa Commune, Vinh Tuong District, Vinh Phuc Province, is polluted. Of the various pollutant sources, wastewater from piggery farms contributes the most potent contaminants. Treating the effluent is believed to avoid clogging the drainage channel, which can also help drain water and prevent floods. The findings showed that surface water samples taken from a fish pond and piggery were polluted, as evident from COD and TSS values that exceeded the technical regulations, i.e., 3–4 and 3 times higher than their maximum allowable levels in 08:2015/BTNMT (B2) and 1.5–2 and 6 times higher than in QCVN 62:2016/BTNMT (A). However, the Phan River sample shows good water quality, as all the parameters observed are lower than their maximum permitted levels. Therefore, a floating wetland treatment system with an area of 500 m^2 and water hyacinth has been proposed as a technical solution for improving the piggery effluent to meet the standards regulated in QCVN 08:2015/BTNMT, B2, and QCVN 62:2016/BTNMT, A.

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