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ASSESSMENT OF LIVESTOCK WASTEWATER TREATMENT EFFICIENCY WHEN USING AN ANAEROBIC DIGESTER COMBINED WITH A BIOLOGICAL POND IN NAM ANH, NGHE AN, VIETNAM

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ABSTRACT

Aim of the study

This study focuses on assessing the efficiency of an anaerobic digester combined with a biological pond in order to provide overview data that can be used as a reference for similar studies in Nghe An province.

Material and methods

Wastewater properties at 3 stages of livestock wastewater treatment process (at the input, after passing through the digester, after passing through the biological pond) in Nam Anh were investigated. A total of 81 samples were collected across 9 locations between March and May 2020. Shapiro-Wilk test ($\alpha = 0.05$), Kruskal-Wallis test and Dunn test ($\alpha = 0.05$) were preformed to estimate the significance differences. Cluster analysis was applied with the view to comparing the parameters between the sampling locations, and in order to classify the respective locations.

Results and conclusions

The results have shown that all parameters by far exceeded the allowable limit specified by the QCVN 40:2011/BTNMT and TCN 678–2006 norms. The wastewater after being treated by anaerobic digester was significantly reduced. The treatment efficiency for BOD5 was 66–73%; for COD, it was 74–80%; 78–84% for SS; 10–27% for TN; 7–25% for TP; and for coliform, it ranged between 28.2–85.3%. Wastewater after being treated through the digester combined with the biological pond displayed a very high treatment efficiency: 95–97% for BOD5; 96–97% for COD; up to 96–97% for SS, 45–57% for TN; 35–70% for TP; between 77.4–98.4% for coliforms. The treatment efficiency demonstrated a linear correlation between object locations. Applying an anaerobic digester in combination with a biological pond has proven to be a highly effective solution, which should be prioritized in the treatment of livestock wastewater.

Keywords: efficiency, cluster analysis, anaerobic digestion, statistical analysis

INTRODUCTION

Along with the rapid development of the economy, the environmental pollution has become an urgent problem we are facing today. Livestock is one of the sources of waste, which pollutes the environment. The livestock industry in recent years has been developing rapidly in terms of both quality and scale. Despite that development, there are many shortcomings in the management and use of livestock-gener-

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ated waste in farms (McNab et al., 2007; Szogi et al., 2006). Some large farms have taken measures to treat livestock waste but there are still some farms that have failed to do so, especially small-scale livestock farms (household scale). One of the reasons is that those farmers do not understand the importance of waste treatment. Funding for waste treatment is still low and the law on waste treatment is still inconsistent – which makes itdifficult to apply and to enforce. Small livestock farms are also one of the reasons why waste management and treatment still poses such a significant problem (McKendry, 2002a, b). In order to reduce rural environmental pollution, an effective solution would be to use anaerobic digesters in households. The biogas thus produced can be used for cooking and the source of light in the household. Animal waste is treated in a closed cellar, avoiding stench, and any remaining residue that can be used as fertilizer (Muller et al., 2007).

The biochemical conversions that occur in anaerobic digester are a complex process involving hundreds of intermediate reactions, each of which is catalysed by an enzyme or a catalyst (USDOE, 2002). These degradation processes can be performed by either anaerobic or photosynthetic microorganisms, producing biogas along with residual by-products in the solid/slurry phase as well as liquid waste. These by-products are rich in nutrients and can be used as an alternative fertilizer. The growth and development of all microorganisms share common requirements: they need water, energy, carbon, nitrogen, and mineral compound sources. These are the basic elements needed for growth, which these microorganisms cannot synthesize on their own. In other words, the elements listed above constitute growth factors. In addition, physical factors can participate in the nutritional process, and they can hinder or create favourable conditions for the growth of microorganisms. These factors include temperature, pH, oxygen, pressure, humidity, light and energy-carrying rays (Chen et al., 2002; Kashyap et al., 2003). The growth, reproduction and metabolism of microorganisms are closely related to external conditions, which include a series of different factors that interact with each other (Umetsu et al., 2005; Beddoes et al., 2007). Wastewater treatment in biological ponds is the simplest and most commonly applied treatment method. It is a method that does not rely on high-level technology; it requires low investment capital, low operating costs, and simple system management. The scientific foundation of the aforementioned method is based on the self-cleaning ability of water, mainly resulting from the activity of microorganisms in the water and other aquatic organisms. The waste is broken down into gas, solid and water. Thus, the wastewater purification process is not only an aerobic process but also a facultative anaerobic process (EPA, 2011).

Nowadays, anaerobic digestion technology is most common in low-income agricultural countries. For instance, six to eight million home-scale anaerobic digesters are used in China and India to provide biogas for cooking and lighting (IEA, 2001). Also in some African countries, anaerobic biodigesters are popular in most areas where livestock is the predominant form of agricultural production. These digesters are typically small and medium sized with gas production capacity starting at below 100 m^3/day to larger units with gas production capacity up to 500 m^3/day (Akinbami et al., 2001). AD focused energy programs are being investigated in detail in many high-income industrial countries. In fact, there are now more than 800 on-farm digesters operating in Europe and North America (IEA, 2001). In addition, energy production using AD technology has been studied extensively in Denmark, where there are many centralized livestock waste digesters. The supply ranges from about 50–500 tons/day of manure mixed with 10–30% of organic waste received mainly from industrial production. Daily gas production from each plant is typically in the range of 1000–15 000 m^3 (Maeng et al., 1999). The operation and installation of biogas plants is a promising investment when assessed against socio-economic criteria – as demonstrated by several cases in Sweden, the Netherlands, and Germany (Dagnall, 1995; Tafdrup, 1995).

This study was conducted in Nam Anh commune, Nghe An province, Vietnam. Nam Anh is an agricultural area with many characteristics typical of rural Vietnam. According to statistics, the potential development of anaerobic digesters in Nam Anh at household and industrial scale is very large. As of October 2019, this commune had 3085 buffaloes, 3959 cows, 11 695 pigs, 299 394 poultry, and approximately thousand head each of goats and deer. Collectively they are responsible for discharging into the environment 71 845 tons of solid waste, 46 655 tons of liquid waste and hundreds of million m^3 of gaseous waste annually (DARDNA, 2019). If this amount of waste is not treated, it will cause serious environmental pollution. A quick assessment shows that, if converted into biogas, the aforementioned waste would yield more than 5.38 million m^3 of biogas per year, equivalent to about 3.93 million litres of gasoline (DARDNA, 2019). The anaerobic digester used in Nam Anh is composed of four parts: the material input, the waste output, the anaerobic digestion zone, and the gas storage zone. The input is where the digester's input material is stored and distributed. The solid waste and wastewater, which are the products of anaerobic decomposition, are stored in the output before being taken out. The materials are stored and the anaerobic digestion processes take place in the anaerobic digestion zone. The gas storage zone has the function of accumulating gas generated by anaerobic decomposition (mainly CH_4 and CO_2, H_2S, and H_2O). The structure of the digester is shown in Figure 1.

In Nam Anh, the application of anaerobic digesters to wastewater treatment began many years ago and it is becoming increasingly widespread in all localities within the commune. However, the actual operation of these facilities still poses many problems. Wastewater, waste solid, and gas after treatment have not been optimized. There are currently no reports evaluating the effectiveness of the digesters being used. We hypothesized that the treatment efficiency of the system may vary from region to region and by pollution parameter, depending on specific variables such as system operating conditions, pond size, or input wastewater characteristics. Therefore, this study focuses on assessing the efficiency of the anaerobic digester combined with a biological pond in order to provide overview data that could be used as a reference for similar studies in the Nghe An province.

MATERIALS AND METHODS

Study area

Nam Anh commune is located in the south of Nghe An province, about 20 km from Vinh City. On the east, it borders the Nam Xuan commune; on the west, it borders the Nam Thanh commune; on the south, it borders the Xuan Hoa commune; and on the north, it borders the Nghi Cong commune – all in the Nghe An province. The natural area of the commune is nearly 12.95 km², and it is divided into 9 hamlets. The total number of households is 2174, and the population

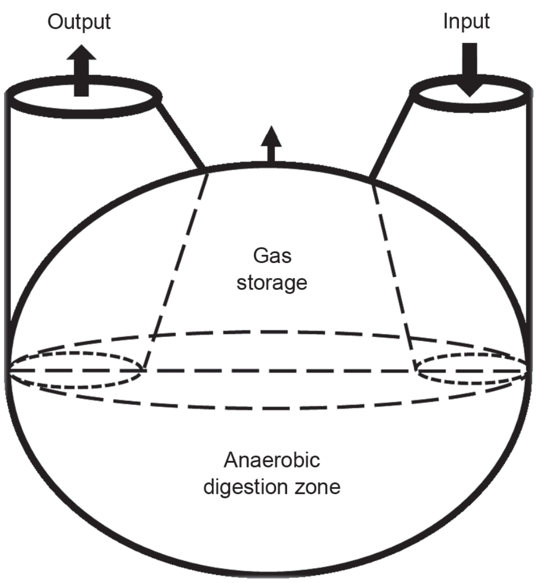

Fig. 1. The structure of the anaerobic digester

counts 8173 people, of which more than 70% are engaged in agricultural production. The geographical location of the Nam Anh commune is shown in Figure 2. More than 50% of the households have used digesters combined with biological ponds. The digester volume is 7–9 m^3, and the pond area is 120–500 m^2. The digester volume and biological pond area of 9 locations are presented in Table 1.

Selection of sampling points

Sampling points were selected at 9 households representing 9 hamlets in the Nam Anh commune (Fig. 2). Prerequisites for households' selections included the size of livestock (small-scale livestock farms were designated) and the use of an anaerobic digester combined with a biological pond. The locations of the sampling points are described in Table 2.

Table 1. Information about the digester and biological pond in the study locations

Location	Digester volume (m^3)	Pond area (m^2)
X1	7	120
X2	7	350
X3	9	250
X4	9	220
X5	9	200
X6	9	450
X7	7	250
X8	9	500
X9	9	300

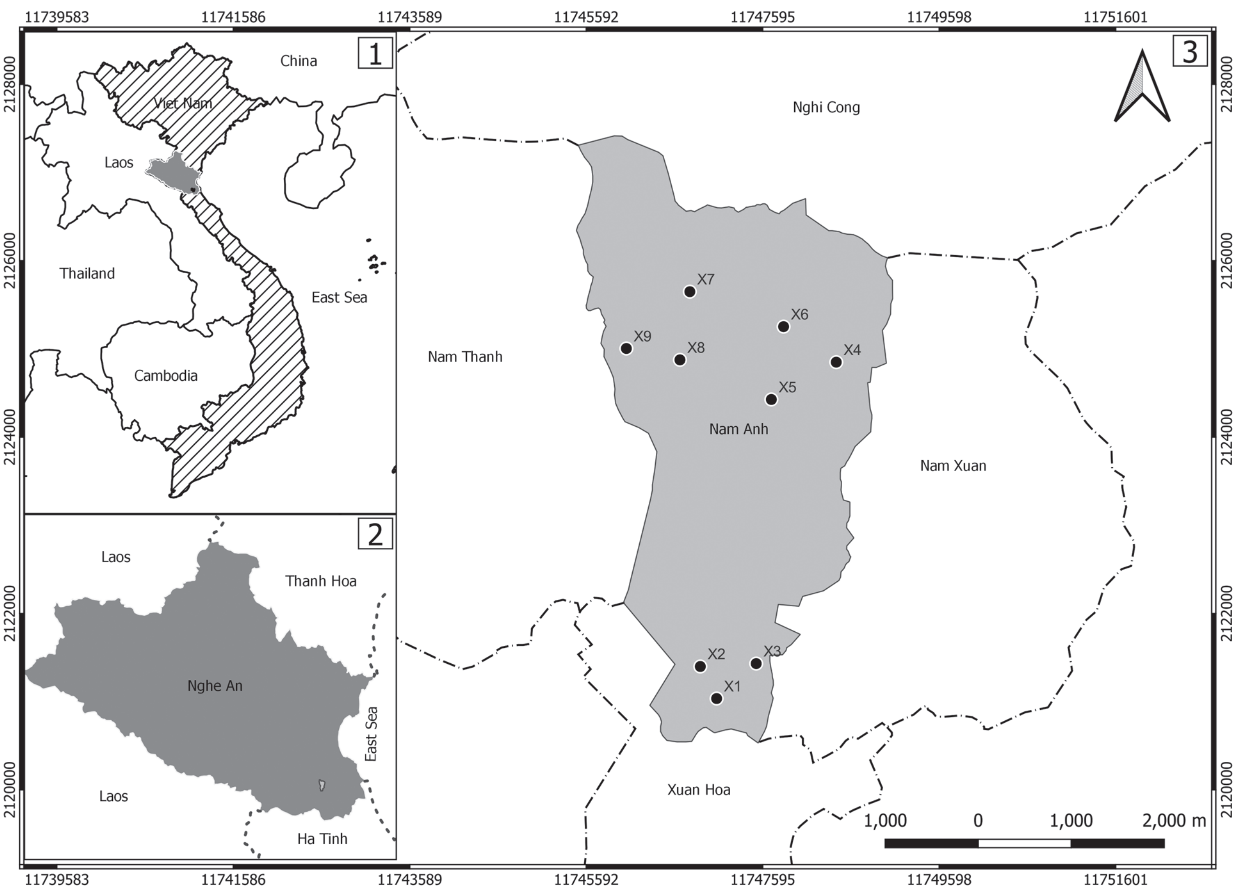

Fig. 2. Map of study area and sampling sites

Table 2. Coordinates of sampling points

Location	X1	X2	X3	X4	X5	X6	X7	X8	X9
Longitude	265184.64	265013.53	265615.23	266516.43	265813.19	265954.39	264950.80	264835.23	264260.59
Latitude	2071134.57	2071479.19	2071502.83	2074712.27	2074322.55	2075099.03	2075485.10	2074758.12	2074886.72

Sample collection

Wastewater samples were collected over a period of 3 months in 9 households in the following months: 03/2020, 04/2020 and 05/2020. In each household, 3 samples were taken including 1 input wastewater sample before the anaerobic digester, 1 output wastewater sample after it had passed through the anaerobic digester, and 1 sample at the biological pond. The total number of samples collected was 27 samples per month. Wastewater samples were collected into 250 ml glass bottles and transported to the laboratory immediately for storage at 4°C.

Laboratory analysis

The parameters such as Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Suspended Solids (SS) and coliform were measured in the laboratory according to the standard methods recommended by American Public Health Association (APHA, 1999). TP amount was determined via Ammonium molybdate spectrometric method and the determination of TN by catalytic digestion after reduction with Devarda's alloy. COD was measured using titration method with potassium permanganate. BOD_5 was measured through the amount of oxygen consumed by the bacteria and other microorganisms in a water sample over a 5-day period at 20°C. SS content was measured by using filter paper. Coliform content was determined by in vitro culture method.

Data and statistical analysis

Shapiro-Wilk test ($\alpha = 0.05$) was applied to check whether the variables presented normal distribution or non-normal distribution. In order to estimate the differences in statistical significance, non-parametric analysis was preformed using Kruskal-Wallis test and Dunn test ($\alpha = 0.05$). Cluster analysis was utilized for the normalized data with Ward's method, combining squared Euclidean distances to measure similarities. The hierarchical cluster analysis was applied to define the similarity between different sampling locations. The analysis was accomplished in the R software, and presenting statistical analysis such as mean value and standard deviation. Besides, Microsoft Excel software was also used to draw graphs for each parameter of wastewater quality.

RESULTS AND DISCUSSION

General assessment of input wastewater characteristics

In terms of organoleptic qualities, wastewater was black in colour and had an unpleasant stench. The analysis results of some wastewater quality parameters at the study sites were presented in Table 3. Analytical data showed a high concentration of organic matter in the wastewater. The measured BOD_5 concentration exceeded the allowable limit 3.2–4.9 times of the norm specified by TCN 678–2006 (300 mg $O_2 \cdot l^{-1}$), and 19.2–29.5 times compared with the QCVN 40:2011/BTNMT (50 mg $O_2 \cdot l^{-1}$) norm. COD concentration exceeded the allowable norm 5.76––8.56 times according to TCN 678–2006 (400 mg $O_2 \cdot l^{-1}$), and 15.4–22.8 times according to QCVN 40:2011/BTNMT standards (150 mg $O_2 \cdot l^{-1}$). These results were equivalent to the research outcome obtained by Ton et al. (2008). The ratio of BOD_5/COD was 0.4–0.5. According to Pham (2002), with such a ratio, wastewater contained mainly cellulose, hemicellulose, protein and insoluble starch, and it needed to undergo anaerobic treatment (Ly, 2005; Liotta et al., 2015; Bugajski et al., 2015).

The concentration of suspended solids, nutrients, and micro-organisms all greatly exceeded the allow-

Table 3. The wastewater characteristic at the research locations

Location	BOD_5 ($mgO_2 \cdot l^{-1}$)	COD ($mgO_2 \cdot l^{-1}$)	SS ($mg \cdot l^{-1}$)	TN ($mg \cdot l^{-1}$)	TP ($mg \cdot l^{-1}$)	Coliform (MPN/100 ml) $*10^6$
Input wastewater characteristics (mean ± standard deviation)						
X1	1195±186	2852±842	3756±685	744±64	466±82	117.5±34
X2	1132±402	2304±687	2520±1525	539±211	275±135	39.4±44
X3	1295±55	2811±427	3690±249	626±89	310±104	23.4±13
X4	1423±471	3053±1085	3186±1479	602±157	343±182	44.4±35
X5	1412±427	3425±1227	4002±884	631±176	322±187	82.6±60
X6	960±383	2180±770	2822±1323	652±205	333±197	22.6±21
X7	1218±258	2772±401	3389±1061	624±171	329±153	41.8±29
X8	1049±364	2567±1127	2594±1208	528±106	258±82	36.8±38
X9	1475±206	3123±367	3377±781	671±107	346±133	50.4±41
Output wastewater characteristics at the anaerobic digester						
X1	389±209	558±238	614±173	646±116	421±97	17.25±10.6
X2	312±196	516±286	479±305	457±211	227±122	22.6±10.7
X3	435±165	711±125	741±64	455±130	275±105	6.1±3.2
X4	464±233	700±204	702±149	530±148	274±140	11.3±8.4
X5	486±157	716±107	653±139	540±160	278±208	16.2±12.9
X6	299±158	577±215	576±248	584±224	309±194	16.25±9
X7	391±54	654±70	685±178	501±230	273±133	17.1±8.2
X8	280±148	503±232	463±219	449±45	194±70	15±12
X9	421±50	716±84	669±136	576±118	274±120	13.15±15.5
Output wastewater characteristics at the anaerobic digester combined with the biological pond						
X1	54±20	101±34	119±33	370±27	224±43	3.87±0.06
X2	48±15	97±23	86±52	252±86	137±65	8.92±0.06
X3	56±15	103±15	118±18	294±12	162±77	2.41±0.04
X4	58±21	100±22	110±32	286±79	174±90	0.89±0.09
X5	47±11	99±17	101±42	347±74	208±103	1.34±0.08
X6	46±13	91±19	105±51	289±129	99±62	4.57±0.03
X7	41±5	96±12	114±45	289±114	172±77	1.71±0.03
X8	45±6	96±1	79±31	255±30	137±56	1.63±0.04
X9	62±15	106±6	116±34	289±18	178±71	1.79±0.09
TCN 678-2006*	**300**	**400**	**500**	**150**	**20**	**0.005**
QCVN 40:2011/ BTNMT**	**50**	**150**	**100**	**40**	**6**	**0.005**

***** TCN 678–2006: Sanitation standards of livestock waste water. Minister of Agriculture and Rural Development, Vietnam.

****** QCVN 40:2011/BTNMT: National technical regulation on industrial wastewater. Minister of Natural Resources and Environment, Vietnam.

able standards. Compared with TCN 678–2006, SS concentration exceeded the norm by the factor of 5–7.5, TP concentration exceeded the norm by the factor of 12.9–23.3 times, and TN concentration exceeded the norm by the factor of 3.5–5. According to QCVN 40:2011/BTNMT standards, SS concentration exceeded the norm 25.2–40 times, TP concentration exceeded the norm 43–77.7 times, and TN concentration exceeded the norm 13.2–18.6 times. The density of coliform was extremely high, exceeding both QCVN 40:2011/BTNMT standard and TCN 678–2006 standard by a factor of 23 500, and varying greatly between the surveyed sites.

With such characteristics, if wastewater is not treated, it will gravely affect the surrounding environment, human health, and livestock.

Efficiency of the anaerobic digester

Basically, the wastewater after being treated i.e. passed through the digester was light black or blue-black, with little odour. The results of the wastewater quality analysis were shown in Table 3.

In general, wastewater had high pollutant content. The basic parameters of wastewater all exceeded the allowable standards multiple times. Compared with the standards TCN 678–2006, concentration of organic matter was slightly exceeded in some locations: BOD_5 and COD exceeded the norm by a factor of 1.04–1.62 and 1.3–1.8, respectively. The SS concentration at some locations was exceeded 1.2–1.4 times. Nutrient concentration was quite high: TN and TP exceeded the norm by a factor of 3–4.3, and 9.7–20, respectively. Coliform still had a high concentration, exceeding the norm as much as 1220–4520 times.

Compared with QCVN 40:2011/BTNMT, concentration of organic matter exceeded the norm by a factor of 5.6–9.7 (for BOD_5), and 3.4–4.8 (for COD). Nutrient concentration exceeded the norm 11.2–16.2 times (for TN), and 23–70.2 times (for TP). The concentration of SS exceeded the norm 4.6–7.4 times. Coliform had a concentration exceeding the norm by a factor of 1220–4520.

Comparative results showed that water after being treated through the digester was not suitable for releasing into the environment. With a high concentration of pollutants, such wastewater will contribute to the deterioration of the environmental quality of the receiving source. In particular, the risk of causing eutrophication of water sources is very severe. High concentrations of coliform (>10^6 MPN/100 ml) can be hazardous to both human and livestock health (Kasumba et al., 2020).

In theory, the concentration of pollutants in wastewater will decrease after passing through the digester. The data also shows that the obtained water had a lighter colour, and was less odourous than the original input. It demonstrably follows that the digester was effective in reducing the pollutant concentration. The treatment efficiency of the digester is shown in Figure 3 for each parameter. Figure 3 also shows a linear correlation between the sampling locations.

The concentration of organic matter in the wastewater was significantly reduced after it had passed through the digester. The treatment efficiency for BOD_5 was 66–73%, and for COD it was 74–80% (Fig. 3 for BOD_5 and COD). These results are consistent with previous studies conducted by Ton et al. (2008) and Ly (2005). During anaerobic digestion process, microorganisms mainly use organic matter to produce final products (CO_2 and CH_4), and they use only a small part to synthesize new cells (Makowska, Maciejewska, 2016). The removal of organic matter in wastewater due to microbial decomposition significantly reduced the colouring and odour of wastewater. Differences in organic matter removal efficiency between digesters may be due to their different operating modes and conditions (Wang et al., 2017; Cupak et al., 2019).

Similar to organic matter, the concentration of SS decreased sharply after passing through the digester. The SS treatment efficiency of the devices reached 78–84% as shown in Figure 3 for SS. The decrease in solids' concentration was mainly due to microorganisms decomposing organic particles, and the remaining parameters were decreased due to particles of inorganic origin being deposited in the bottom sludge. The difference in SS treatment efficiency was due to the different conditions and input materials between the digesters.

Figure 3 for TN and TP showed that after the treatment through the digester, the concentration of nutrients decreased slightly, reaching only 10–27% for TN, and 7–25% for TP. The results of this study are consis-

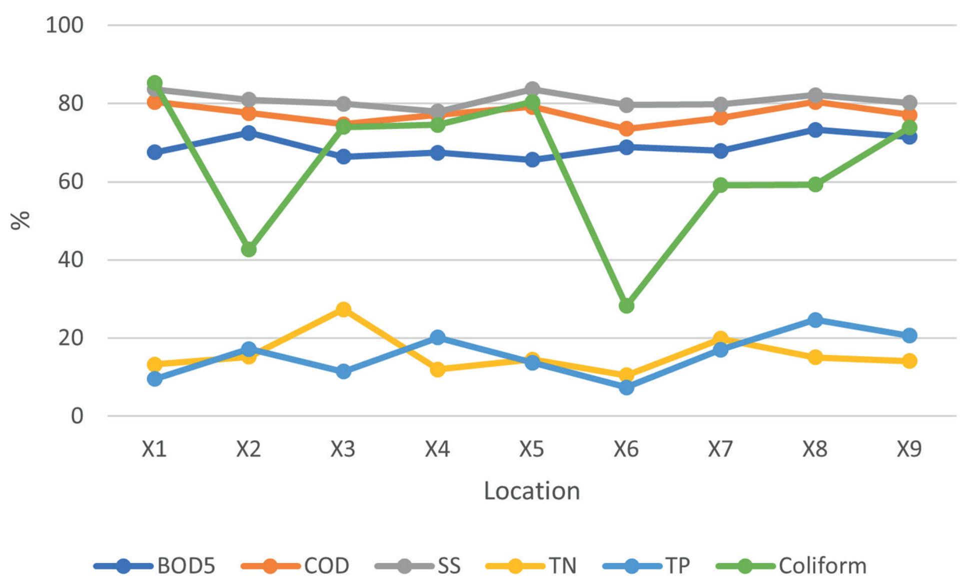

Fig. 3. Treatment efficiency of the anaerobic digester

tent with the results reported by Ton et at. (2008) and Kaczor (2020), where the TN concentration decreased by 10.1% to 27.46%.

With high temperature and rather long retention time in the digester, pathogenic microorganisms will be reduced by between 80% and 100% after being treated (Paśmionka, 2020). Coliform density measured after digester ranges between 28.2% and 85.3%. The treatment efficiency varies greatly across devices. This difference may be due to the influence of environmental factors, the leak tightness of the device, or contamination from other sources. In fact, the cage area is very humid due to leftovers, overflowing water or proximity of drains; therefore the possibility of re-contamination is quite high (Costa et al., 2007).

Efficiency of the anaerobic digester combined with the biological pond

Wastewater after being treated through the digester continues to be treated at the biological pond. Here, pollutants with high concentrations have not been thoroughly treated, while pollutants such as organic matter and nutrients were treated with a significant reduction. In sensory terms, the water at the biological pond was relatively clear, it had no black or blue-black colouring and no odour. The results of the wastewater quality analysis are presented in Table 3.

From the data presented in the table, we can conclude that the ability to treat pollution in wastewater at the biological pond was relatively good. However, the concentration of nutrients (N, P) was still high, and whereas the coliform index had decreased sharply, in general terms, it remained high. Compared with the TCN 678–2006 standard, the parameters of BOD_5, COD, and SS were lower than the prescribed limit. However, the parameters of TN exceeded the norm 1.68–2.5 times, and TP exceeded the norm 5–11.2 times. Coliform content decreased significantly, but still exceeded the allowable limit by a factor of 178–1784. Compared with the QCVN 40-2011/BTNMT standard, COD and BOD_5 values obtained were lower than the specified maximum limit, whereas SS concentration was slightly exceeded. The concentration of TN was exceeded 6.3–9.3 times. TP concentration was exceeded 16.5–37.3 times. Coliform index was exceeded 178–1784 times.

Wastewater after treatment at the biological pond had a much lower organic matter content than the input, which means that the organic matter treatment efficiency of the digester system combined with the biological pond was very high: 95–97% for BOD_5, and 96–97% for COD. The organic matter removal efficiency for COD_5 and COD is presented in Figure 4. The efficiency of organic matter removal between the systems varied, because the performance of each system is different and it depends on the size and biological activity in the pond (Stein, Malone, 1980). The SS treatment efficiency was up to 96–97%, which was much higher than that of the anaerobic digester only (78–84%). The SS treatment efficiency is shown in Figure 4 for SS. Other than the process at the digester, the nutrients (N, P) in the biological pond were better removed, because the nutrients were used by the flora and fauna in the pond. The efficiency of N and P treatment increased to 45–57% with TN, and 35–70% with TP. The nutrient treatment efficiency for TN and TP is shown in Figure 4. The nutrient treatment efficiency was dissimilar to the systems' efficiency due to the differences in the N, P absorption capacity of the ponds. This capacity depends much on the characteristics and hygiene of the pond. Ponds with rich biological systems have a higher capacity to consume nutrients than ponds with poor organisms (Stein, Malone, 1980). The majority of coliforms in wastewater were treated at biological ponds. Therefore, the coliform treatment efficiency reached 77.4––98.4%, much higher than that of the digester alone. The causes for that result lie in the photosynthetic activity of algae in the pond. Carbonate and bicarbonate ions generate reactions that provide a lot of carbon dioxide to the algae, and many hydroxyl ions are released, and thus the pH of the water can be increased causing the water to become strongly alkaline. The process of photosynthesis increases the pH in parallel with the intensity of radiation in large ponds. This is a factor that inhibits the growth of pathogenic bacteria (Popowicz, Koszelnik, 2015). The treatment efficiency for the coliform content is shown in Figure 4. The difference in treatment efficiency between the systems is due to the different activity levels of the pond biota and the different sizes of the ponds (Stein, Malone, 1980). The linear correlation between sampling locations is also shown in Figure 4.

Statistical analysis

The parameters in processing (Input, digester output, and pond output) such as BOD_5, COD, TN, TP, Coliform, have been presented in Figure 5. Minimum and maximum values are shown with whiskers that represent the lowest and the highest value. Differences between the parameters in processing are shown by median, according to Kruskal-Wallis test and Dunn test ($\alpha = 0.05$).

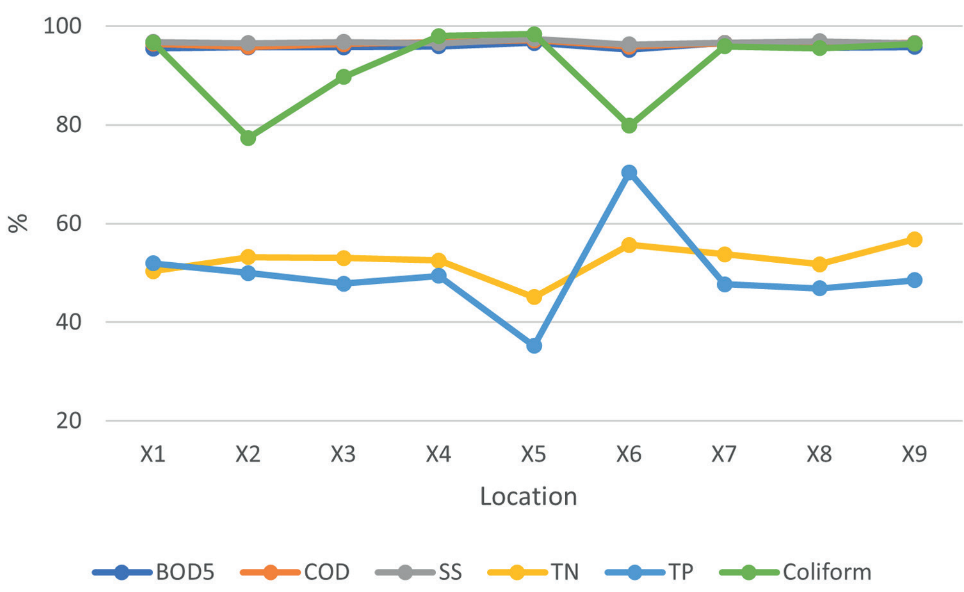

Fig. 4. Treatment efficiency of the anaerobic digester combined with the biological pond

a) BOD_5, Kruskal-Wallis test (chi-squared = 71.146, df = 2, p = 3.555e-16) showed that there is statistically significant difference between the BOD_5 values in processing. The Dunn test demonstrated that BOD_5 value represents statistically significant difference between the Input and the Digester Output (p = 7.41e-5), between the Input and the Pond Output (p = 9.95e-17), and between the Digester Output and the Pond Output (p = 7.41e-5).
b) COD, Kruskal-Wallis test (chi-squared = 71.135, df = 2, p = 3.575e-16) delivered the statistical difference between the COD value in processing. The Dunn test revealed statistically significant difference between the Input and the Digester Output (p = 7.42e-5), between the Input and the Pond Output (p = 9.95e-17), and between the Digester Output and the Pond Output (p = 7.41e-5).
c) SS, Kruskal-Wallis test (chi-squared = 71.13, df = 2, p = 3.584e-16) presented the statistical difference in processing. The Dunn test revealed statistically significant difference in the SS value between the Input and the Digester Output (p = 7.43e-5), between the Input and the Pond Output (p = 1.00e-16), and between the Digester Output and the Pond Output (p = 7.43e-5).
d) TN, Kruskal-Wallis test (chi-squared = 49.013, df = 2, p = 2.275e-11) showed the statistical difference between the TN value in processing. The performed Dunn test revealed statistically significant difference between the Input and the Pond Output (p = 3.69e-11), and between the Digester Output and the Pond Output (p = 2.72e-6).
e) TP, Kruskal-Wallis test (chi-squared = 21.935, df = 2, p = 1.725e-05) revealed that there is the statistical difference in the processing. The Dunn test demonstrated statistically significant difference between the Input and the Pond Output (p = 1.7e-05), and between the Digester Output and the Pond Output (p = 0.00321).
f) Coliform, Kruskal-Wallis test (chi-squared = 57.029, df = 2, p = 4.133e-13) showed the statistical difference between the Coliform value in processing. The Dunn test revealed statistically significant difference in Coliform value between the Input and the Pond Output (p = 4.32e-13), and between the Digester Output and the Pond Output (p = 1.45e-6).

Cluster analysis

Figure 6a presented the correlation between 9 sampling locations (X1 to X9) with input wastewater data. It showed 3 statistically significant clusters. The first cluster covers 5 locations (X1, X3, X4, X7, X9). The second cluster in fact represents only 1 location (X5). The third cluster comprises 3 locations (X2, X6, X8). Figure 6b described the correlation of locations with wastewater data after the digester combined with a biological pond, and it shows 3 significant clusters. The first cluster covers 2 locations (X1, X5). The second cluster contains 3 locations (X2, X6, X8). The third cluster includes 4 locations (X3, X4, X7, X9).

The results showed a similarity in the cluster of sampling sites between the input wastewater and in the wastewater after it has passed though the digester combined with the biological pond. Clusters X1, X5 are typical for the high concentration of pollution parameters. Clusters X2, X6, X8 are locations with low parameters, and the remaining cluster includes positions X3, X4, X7, X9 with average parameter values. Moreover, the analysis also revealed the dependence of the treatment efficiency of the systems on the input wastewater properties.

CONCLUSIONS

These research results showed that the input wastewater had a very high pollutant content. The measured parameters exceeded the allowable limit multiple times, according to the specification of the TCN 678–2006 and QCVN 40:2011/BTNMT standards.

After being treated in the anaerobic digester, the wastewater has a significantly decreased but nevertheless still high pollutant content. The basic parameters of wastewater all greatly exceeded the allowable standards. The treatment efficiency for organic matters remained within the range of 66–80%, and for SS, it was within the range of 78–88%. The concentration of nutrients decreased slightly, reaching only a 7% to 27% reduction. Coliform density decreased by between 28.2% and 85.3%.

After being treated by passing through the digester, the wastewater continues to be treated at the biological pond. Wastewater treatment capacity at the biological pond was relatively good. However, the concentrations of nutrients (N, P) and coliform were still high,

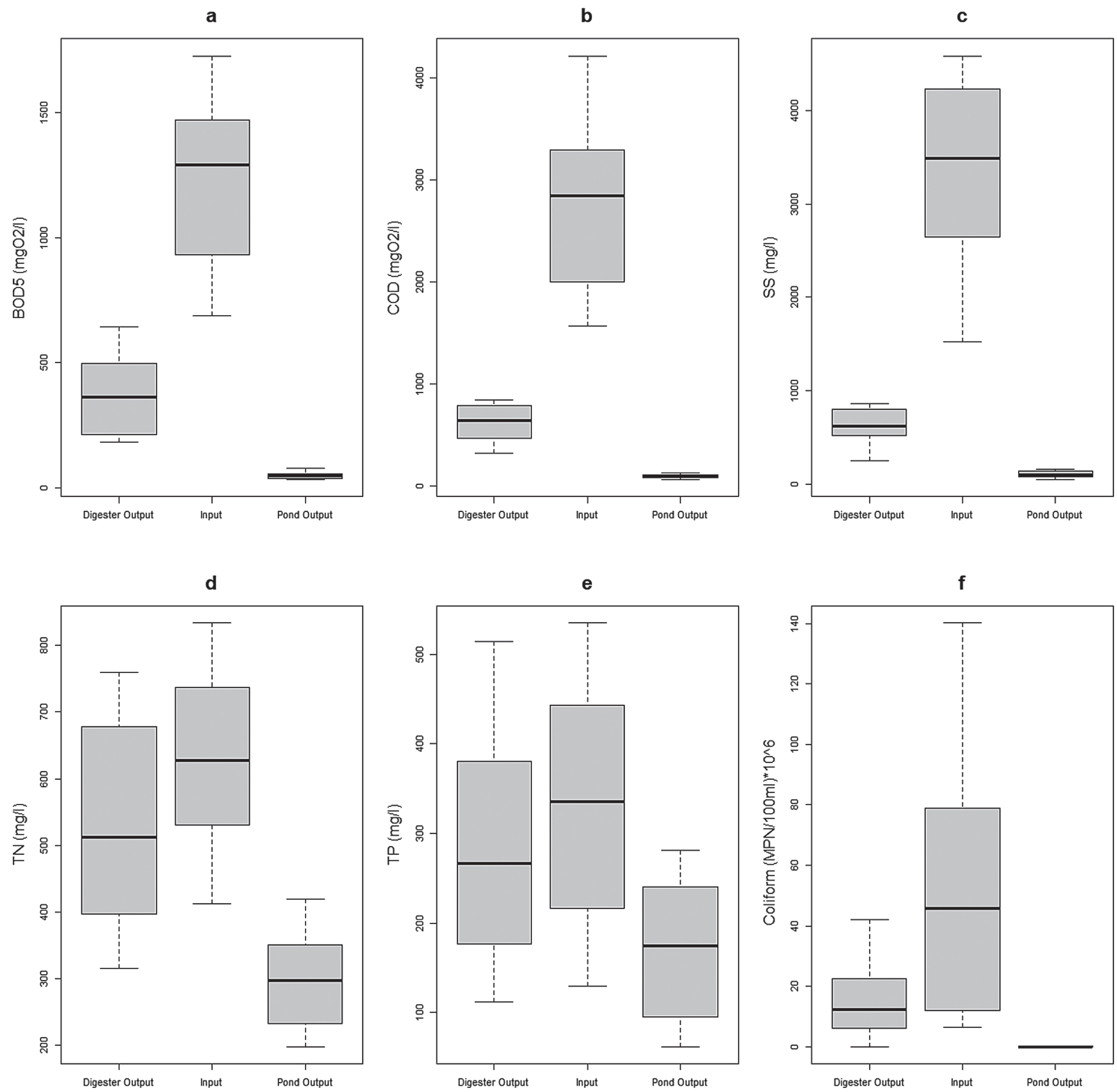

Fig. 5. The parameter values in processing

and they slightly exceeded the allowable limit. The organic matter treatment efficiency was very high, with the reduction by 95% to 97%. The SS treatment efficiency was up to 96–97%. The efficiency of nutrient treatment increased: to 45–57% for TN, and 35–70% for TP. The coliform treatment efficiency reached the level of 77.4–98.4%. A linear correlation between the sampling sites was recorded.

The statistical analysis results showed significant differences between the parameters in processing, and a similarity in the cluster of sampling sites between the input wastewater, and the same wastewater after it

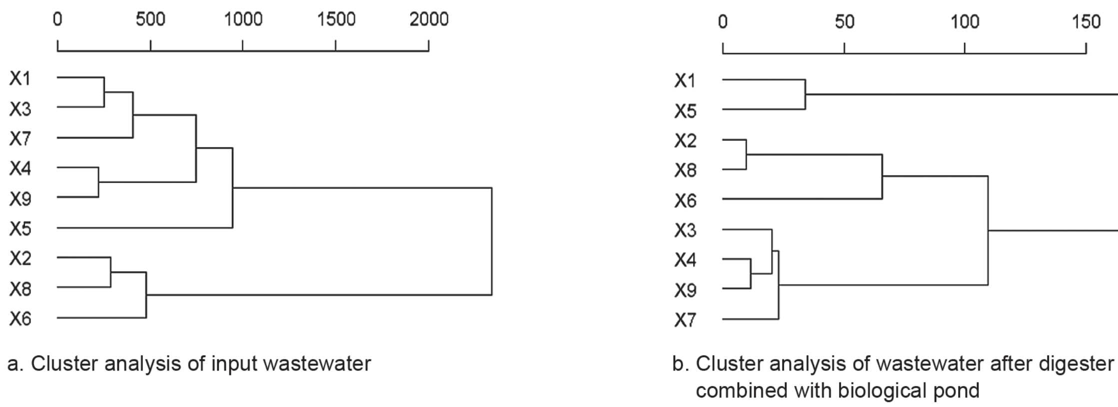

Fig. 6. Cluster analysis dendrogram of sampling locations

has passed through the digester combined with the biological pond. X1 and X5 are typical for the high concentration of pollution parameters. X2, X6 and X8 are locations with low parameter values. Moreover, the analysis also demonstrably showed the dependence of the treatment efficiency of the systems on the input wastewater properties.

Livestock wastewater contains very high concentrations of pollutants. Therefore, applying the anaerobic digestion method combined with a biological pond is a highly effective solution. After the wastewater having been treated, content of most of the pollutants therein decreased significantly, but it still exceeded the allowable limits as specified in the regulations. Thus, operational management and hygiene regime for the digester and the pond need to be paid more attention, in order to improve treatment efficiency. The results obtained from the present study are accurate and consistent, and they can be used as reference data for studies on anaerobic methods in livestock wastewater treatment.

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OCENA SKUTECZNOŚCI OCZYSZCZANIA ŚCIEKÓW INWENTARSKICH W KOMORZE BEZTLENOWEJ POŁĄCZONEJ ZE STAWEM BIOLOGICZNYM W NAM ANH, NGHE AN, WIETNAM

ABSTRAKT

Cel pracy

Badania opisane w artykule skupiały się na ocenie wydajności beztlenowej komory fermentacyjnej połączonej ze stawem biologicznym w celu zebrania ogólnych danych, które będą mogły zostać wykorzystane jako punkt odniesienia dla dalszych podobnych badań w prowincji Nghe An.

Materiał i metody

Zbadano właściwości ścieków na trzech etapach procesu oczyszczania ścieków inwentarskich (w miejscu początkowym – na wlewie, za komorą fermentacyjną oraz za stawem biologicznym) w wietnamskiej gminie Nam Anh. W sumie zebrano 81 próbek w 9 lokalizacjach w okresie od marca do maja 2020 roku. W celu oszacowania różnic istotności wykonano test Shapiro-Wilka ($\alpha = 0{,}05$), test Kruskala-Wallisa i test Dunna ($\alpha = 0{,}05$). Do porównania parametrów pomiędzy lokalizacjami próbkowania oraz do sklasyfikowania poszczególnych lokalizacji wykorzystano analizę skupień (klasteryzację).

Wyniki i wnioski

Na podstawie wyników przeprowadzonych badań stwierdzono, że wszystkie parametry wielokrotnie przekraczały dopuszczalną granicę określoną przez normy QCVN 40:2011/BTNMT oraz TCN 678–2006. Ścieki po oczyszczeniu w beztlenowej komorze fermentacyjnej zostały znacząco zredukowane. Skuteczność oczyszczania dla BZT5 wynosiła 66–73%; 74–80% dla ChZT; 78–84% dla SS; 10–27% dla TN; 7–25% dla TP; a w przypadku bakterii coli wahała się w przedziale 28,2–85,3%. Parametry ścieków po oczyszczeniu, czyli przejściu przez komorę fermentacyjną w połączeniu ze stawem biologicznym, wykazały bardzo wysoką skuteczność oczyszczania: 95–97% dla BZT5; 96–97% dla ChZT; 96–97% dla SS; 45–57% dla TN, 35–70% dla TP; oraz 77,4–98,4% dla bakterii z grupy coli. Skuteczność oczyszczania wykazywała liniową korelację w zależności od lokalizacji poszczególnych obiektów. Zastosowanie fermentacji beztlenowej w połączeniu ze stawem biologicznym okazało się bardzo skutecznym rozwiązaniem, stąd wniosek, że opisany model należy potraktować priorytetowo, planując systemy oczyszczania ścieków inwentarskich.

Słowa kluczowe: wydajność, analiza skupień, fermentacja beztlenowa, analiza statystyczna