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VERTICAL FLOW CONSTRUCTED WETLAND: A TECHNOLOGICAL INNOVATION FOR DOMESTIC WASTEWATER TREATMENT AT PAOAY LAKE, MUNICIPALITY OF PAOAY, ILOCOS NORTE, PHILIPPINES

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ABSTRACT

Wastewater has been a major problem for various communities in the Philippines and worsens as the human population trends upward. Paoay Lake, a water body in the northernmost of the country, is not an exception to this problem. It is one of the country's largest natural lakes and the region's largest and most accessible freshwater for domestic use. The lake is also used for recreation and ecotourism activities. However, with the growing domestic and agricultural sectors, the already contaminated lake is receiving more wastewater generated by households and farming practices; thus termed domestic wastewater. This research sought to introduce a vertical flow constructed wetland (VFCW) as a technological innovation for domestic wastewater treatment at Paoay Lake, Municipality of Paoay, Ilocos Norte, Philippines. It specifically aimed to (1) determine the socio-demographic profile of the communities around the lake; (2) determine the lake's physical, biological, and hydrological characteristics based on the available data; (3) introduce vertical flow constructed wetlands for domestic wastewater treatment; and (4) calculate the flow rate of water extraction by the local households to determine the design and dimension of the wastewater treatment facility. Secondary data were used to achieve the first two objectives, which further revealed the lake's poor water quality. Thus, the introduction of wastewater treatment facilities such as VFCW is deemed very effective and efficient in treating domestic wastewater while considering the lake's overall characteristics during the planning and design; the VFCW can be replicated for other water bodies in the Philippines.

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INTRODUCTION

Background

Paoay Lake, one of the largest natural lakes in the Philippines, is situated in the Municipality of Paoay, Ilocos Norte. It is the region's largest and most accessible freshwater supply, which contains a wealth of diverse biological resources and is considered a scenic and historically significant spot. The lake has a horseshoe-shaped shoreline, with an area of 346.91 ha (3.65 km^2), including the lake water and its immediate surroundings, i.e., the reservation area called Paoay Lake National Park (PLNP). PLNP is home to a diverse range of wild birds, serving as a haven for feathered companions and an essential stopover for migratory birds flying the East Asian-Australasian Flyway. Around 25 species of migratory birds visit Paoay Lake, some coming from as far as China, Japan, and Siberia.

Moreover, PLNP provides academics with an excellent research and observation site for aqua-based, grassland, and understory vegetation studies. The legendary Paoay Lake is also ideal for recreational and ecotourism activities, e.g., boating, picnicking, bird watching, and sightseeing, and nature trips, e.g., excursions, camping, and field trips. Besides, it is a well-known tourist stop when visiting the sand dunes.

Paoay Lake has multiple purposes, including irrigation water, industrial water, recreational area, fish habitat, and domestic water supply. Plots around the lake are intensively cultivated with rice during wet seasons. Corn, tobacco, and vegetables are planted in dry seasons, tapping the lake water for irrigation. In addition to agricultural lands, human settlements are growing near the shoreline. Small-scale aquaculture has also been developed in some parts of the lake as additional income for the local communities.

Research objectives

This wastewater treatment project initiative was intended to use constructed wetlands to address domestic wastewater problems. Here, 'domestic wastewater' refers to Paoay Lake water that is polluted by domestic waste. Specifically, this project aimed:

1. to determine the socio-demographic profile of the local communities around the lake;
2. to determine the lake's hydrological characteristics based on the available data;
3. to introduce vertical flow constructed

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wetlands for domestic wastewater treatment; and

4. to calculate the flow rate of water extraction by the local households to determine the design of the wastewater treatment facility.

MATERIALS AND METHOD

Research locale

The famous Paoay Lake is geographically located between 15°05' and 18°10' N and between 120°31' and 120°36' E (Figure 1). The lake and its immediate surroundings are 346.91 ha (3.65 km^2), bordered by four villages: Suba to the north, Nangguyudan to the northeast, Nagbacalan to the southwest, and Sungadan to the South. Morphologically, rough topography edges the lake, with terrains sloping towards its outline. The highest elevations (61–80 masl) are in Sungadan Village and some parts of Nagbacalan Village.

Figure 1. Paoay Lake and its immediate environments

Nagbacalan has the highest population among the villages around the lake. Therefore, it is expected to produce more domestic wastewater than other less populated villages. Besides, only a few households have septic tanks, meaning that most household wastes in the area are disposed of directly to the lake. As such, Nagbacalan is the main area and focus of the project, designed to address its domestic wastewater problems. Secondary to Nagbacalan are the three other villages abutting the lake: Nangguyudan, Suba, and Sungadan

Data collection

The study made use of secondary data to determine two parameters: (1) the socio-economic characteristics of the local people in the four villages and (2) the lake's hydrological parameters, obtained from the Department of Environment and Natural Resources (DENR)—a government agency responsible for governing and supervising the exploration, development, utilization and conservation of the country's natural resources. Based on these parameters, the wastewater treatment design was determined and introduced as a strategy to address the domestic wastewater problem at Paoay Lake.

RESULTS AND DISCUSSION

Socio-economic characteristics of the local population

Based on the Community-Based Monitoring System (CBMS), in 2018, the total population of the four villages was 5,922 as listed in Table 1. Nagbacalan had the largest population size, 2,842 people from 663 households, meaning the average household size was 4.7 or rounded up to 5. In contrast, Nangguyudan had the lowest population of 672, comprising 176 households with an average size of 4.9 (or 5).

Hydrological characteristics of Paoay Lake

Water analysis at all the observation points revealed that Paoay Lake contained *E. coli*, ranging from 2,840 HPC (heterotrophic plate count) to 5,780 HPC, considerably above its maximum allowable limit, 500 HPC. The lake water samples were collected near the four villages (Nangguyudan, Sungadan, Suba, and Nagbacalan). The highest bacteria concentration was observed in Nagbacalan (5,780 HPC). Pathogenic bacteria and viruses in the lake are transported in with untreated human sewage due to insufficient septic tanks, seepage from on-site wastewater disposal systems (accommodating wastes from settlements, industrial, and commercial establishments), and animal feces that is expected to increase with the more livestock breeding and production in the villages.

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Table 1. Population distribution, household number, and average household size of the four villages in the immediate surroundings of Paoay Lake.

Village	Population	Number of Households	Average Household Size
Nagbacalan	2842	663	4.7
Nangguyudan	672	176	4.9
Suba	1435	374	4.8
Sungadan	973	247	4.4

Table 2. Chemical properties of the Paoay Lake water samples**.**

Chemical Parameter	Parameter Value	Normal Value (Standards by DAO 2016-08 WQG and GES)
pH	8.2	6.5–9.0
Dissolved oxygen (ppm)	7.2	5.0
Nitrate (mg/L)	0.1	7.0
Phosphate (mg/L)	0.02	0.5

Table 2 presents the chemical characteristics of the water samples collected from several sites on the lake. Results showed that the dissolved oxygen (ppm) was higher than 5.0 ppm, the standard set by the Philippine Government in the surface water quality guidelines and general effluent standards document.

Wastewater treatment conditions

Paoay Lake is surrounded by human settlements and agricultural lands that dispose of improperly treated wastewater. The wastewater may contain soaps and detergents, and without a proper drainage and treatment system, it likely contaminates the lake. Aside from domestic water (greywater), the lake catchment area is intensively used for agricultural activities (i.e., livestock and vegetable production).

Discontinuous farm waste disposal management and intensive fertilizer applications are examples of how agricultural practices can harm the environment and, eventually, pollute the lake when carried with surface runoff downstream. Also, suboptimal waste disposal in hog farming can degrade water stability. Hence, it is necessary to conceptualize a plan for solving domestic wastewater issues.

Nutrient pollution, which promotes eutrophication, is another serious hazard to the lake. Surface runoff that transports nitrogen and phosphorus from fertilizers and untreated wastewater downstream induces excessive nutrient enrichment and eutrophication. Some practical solutions are to control erosion and establish agricultural and soil management systems, such as maintaining permanent soil surface cover and implementing soil conservation programs.

Furthermore, domestic and industrial wastes are believed to be the most significant contributors to the lake's water pollution, especially considering that septic tanks and other sanitation facilities in the study area are categorically inadequate. As the number of people living in the catchment grows, more wastewater will enter the lake. Moreover, during rainstorms, surface runoff and flood water will carry more pollutants to the lake, affecting its capacity and, thus, minimizing productivity. For these reasons, without proper treatment, domestic waste will continuously flow to the lake as the leading cause and source of its pollution. To address this problem, technological innovations and interventions must be included in the wastewater treatment options.

Applicability of vertical flow constructed wetland

Based on the lake's chemical properties, typical pollutants, and the region's waste problem, the lake water (i.e., domestic wastewater) requires improvement instead of complete treatment. Therefore, this project particularly selected the vertical flow constructed wetland (VFCW) as the ideal and best option to treat domestic wastewater. The reasons for this selection are as follows:

1. VFCW is more versatile than other types of CWs and proves effective and efficient in reducing BOD, suspended solids, and pathogens in domestic wastewater based on previous studies.
2. Nagbacalan has the highest number of households of the four villages; thus, the constant power supply required for the CW operation would not be a substantial problem. This is to ensure the treatment facility continues to function properly.
3. The location of the treatment facility is not prone to flooding during wet months.

VFCW requires a relatively small

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space compared with other CWs, meaning no shortage of or competition in space, which is especially preferable since the area is intended for agricultural production. This decision will ensure that the villages can continue producing food while maintaining good wastewater management.

VFCW design, capacity, and dimension based on the flow rate of water extraction

The schematic of VFCW, the most sophisticated constructed wetland, is presented in Figure 2. Wastewater or contaminated water first flows into a primary treatment facility, which uses a bar screen. Bar screens remove solid wastes, such as plastics, rags, larger food particles, and sticks, so as to protect the other equipment in the treatment plant and prevent clogging. The schematic of the bar screen is shown in Figure 3. Afterward, the effluent from the primary treatment is fed onto the surface of the constructed wetland (secondary treatment). The influent flows through the filter matrix (soil and gravel) to the bottom and is collected in a drainage pipe that is maintained at a 1% slope. The plants should also be regularly monitored to make sure the CW functions properly.

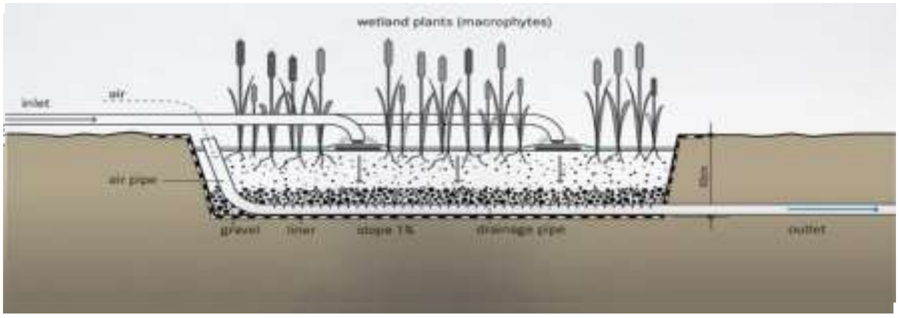

Figure 2. The concept of vertical flow constructed wetland (Source: Tilley et al., 2014)

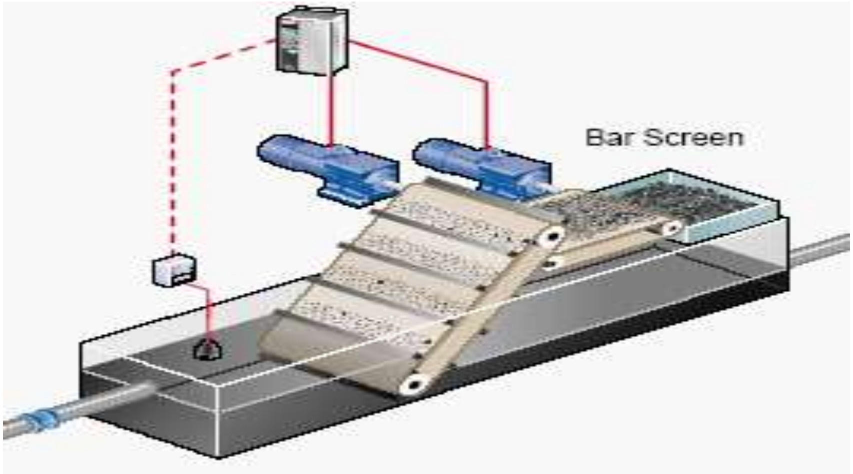

Figure 3. Bar screen (Source: Cvrkota, 2012)

The VFCW design was also determined considering the flow rate of water withdrawal for domestic use in the target village, as visually conceptualized in Figure 4. Because not every household has a sufficient and proper septic tank, black water is directly flown into the lake. Therefore, the proposed wastewater treatment design (black arrows) aims to transport domestic wastewater to primary treatment (S, green box) before being dosed onto the constructed wetland (CW, red box) for secondary treatment. Afterward, the higher-quality effluent will be fed into a storage tank (T, blue circle) to be used by the local population (domestic or agricultural purposes) or returned to the lake.

Figure 4. Wastewater flow in Nagbacalan village
(S: Screening, T: Tank, CW: Constructed wetland)

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The VFCW capacity was calculated from the flow rate of water withdrawal for daily uses, which depends on population size. The projection showed that the Nagbacalan population will increase from 2,842 in 2018 to 3,500 in 2028. The minimum volume of the constructed wetland is based on the maximum flow rate of water extraction for domestic use, i.e., 2 m^3/person/day or 0.2 m^3/person/hour—assuming that each person withdraws water for about 10 hours per day. Therefore, to create a constructed wetland with the most capacity that caters to local water requirements, the highest population in Nagbacalan was used (0.2 m^3/hour/person x 3,500 people). As a result, the maximum volumetric flow rate is 700 m^3/hour. Suba had a population of 1,435 in 2018, projected to increase to about 2,000 in 2028, making the daily water use of the entire village approximately 400 m^3/hour. The Sungadan population will increase from 973 to 1,500 in 2028, requiring a volumetric flow rate of 300 m^3/hour. The 672 people in Nangguyudan were shown to nearly double to around 1,200 in the 2028 projection. This population will require a treatment wetland that can release water at a volumetric flow rate of 240 m^3/hour. These calculations showed several possible scenarios of when the flow rate of the effluent flow from the system is larger than the withdrawal rate. In this case, the excess effluent can either flow back to the lake or be used for other purposes, such as crop water irrigation.

Similar to the capacity, the VFCW dimension was also determined using the flow rate of water withdrawal for daily uses. The VFCW was first constructed in Nagbacalan and replicated in the other three villages (Figure 5). Nagbacalan has a total area of 3.11 ha, while Sungadan, Suba, and Nangguyudan is 3.16 ha, 2.46 ha, and 1.66 ha, respectively. The constructed wetland in Nagbacalan was designed based on the assumption that every person extracts 2 m^3 of water per day. Therefore, with an ideal depth of 1 m^2, the surface area should be 7,000 m^2 (2 m^3/day/person : 1 m^2 x 3,500 people) or 0.7 ha, which is only a small part of the village area (3.11 ha). The VCFW designed for Suba requires a surface area of 4,000 m^2 for 2,000 people, the one for Sungadan is 3,000 m^2 for 1,500 people, and the 1,200 people in Nangguyudan need 2,400 m^2. The surface area should be calculated carefully to accommodate the domestic water needs of all the village residents.

Figure 5. Map showing the target village and the location of the constructed wetland

Evaluation of the wastewater treatment efficiency

After construction, the VFCWs should be regularly evaluated to ensure the water output is clean and safe for various purposes. As such, the efficiency can be determined based on these parameters:

- The amount or number of contaminants removed from the lake water, termed pollutant removal efficiency;
- Pathogen removal (in rate);
- Sustainability of the plants in the CW system;
- The rate of contaminant declines after treatment;
- CW's sustainable function in removing pollutants throughout the years.
- CW's ability to resist changes in both terrestrial and aquatic ecosystems, including whether and to what extent the changes affect its function.

CONCLUSION

Vertical flow constructed wetland (VFCW) is a technological measure to effectively remove pollutants from Paoay Lake, which, according to previous studies, has poor water quality. It is environmentally friendly and less costly than other wastewater treatment techniques. Further, based on the VFCW's function in the target village, it is imperative that the same system is established in the other three villages around the lake. This guarantees that the lake water is clean and safe for agricultural and domestic uses.

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