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STUDY ON THE APPLICABILITY OF FREE WATER SURFACE WETLAND (FWS) SCALE OF WASTEWATER TREATMENT LABORATORY FOR GREEN REST STOPS

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Abstract. The Free Water Surface wetland (FWS) has emerged as a promising technological solution for wastewater treatment in natural environments. The study aimed at investigating the performance of a laboratory-scale Free Water Surface wetland (FWS) unit designed to treat domestic wastewater with a daily capacity of 20 liters. This model can be applied at some rest stops towards creating "Green Rest Stops" on highways. The laboratory experiments on bronze banana plants have shown that the model operates effectively under specific settings and with the characteristics of residential wastewater from public toilets, which has undergone pretreatment through septic tanks. These conditions are conducive to promoting healthy growth in the plants. The FWS model for cultivating canna hybrid plants (Canna generalis) has a total surface area of 0.26 square meters and operates based on the principles of free wastewater flow. The model has a water retention duration of 70 hours, approximately three days. The treatment efficiency for TSS, BOD5, NH4+ - N, and Coliform is 37-53%, 73-77%, 41-46%, and 37-54%, respectively. The treated wastewater complies with the National technical regulations on water quality, QCVN 14:2008/BTNMT (B) standards.

Keywords: underground filtration site, domestic wastewater, wastewater treatment, rest stop, free water surface wetland, reuse.

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1. INTRODUCTION

In our recent studies on green and zero-waste rest stops [1,2], the surveys showed that small-scale rest stops situated at rural locations far from residential zones and comprehensive wastewater treatment facilities must be improved. Urinal wastewater is primarily treated using either a septic tank (ST) or a BASTAF tank (a Baffled septic tank) before being discharged into the environment. Due to the lack of a centralized drainage system, the effluent from the septic tank is discharged into the surroundings. The problem is that the wastewater, following pretreatment by ST, frequently fails to meet specific criteria outlined in QCVN 14:2008/BTNMT (B) standards [3]. As a result, the research team has developed a model of a Free Water Surface (FWS) system for treating wastewater after it has passed through a septic tank. This model is designed to meet environmental standards and align with the specific characteristics of the location. The plantation filter site offers a cost-effective construction investment and low operating expenses. The wastewater treatment process is entirely natural and ecologically benign, without chemicals. Additionally, it generates a natural green system that enhances the ecological surrounding landscape.

The plantation site is specifically developed and constructed to function as a wetland (CW). However, it surpasses conventional wetlands regarding wastewater treatment efficiency, occupies a smaller area, and can be easily managed [4].

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters. In Free Water Surface (FWS), the polluted stream gently flows through the layers of filter, which are below the surface, and interacts with anaerobic, aerobic, and anoxic sections of the active system. When wastewater moves along the root, pollutants are removed by mechanical processes, biodegraded by microorganisms, and absorbed by the plants [5]. Other study has shown that CWs exhibited effective treatment ability for domestic effluents based on several parameters such as COD, BOD_5, and SS, yet the nitrogen- and phosphorus-adsorbing and -metabolizing mechanisms have not been determined due to the shortage of oxygen in the filtration layer having low nitrification [6]. Therefore, this study focuses on TSS (Total Suspended Solids), BOD_5 (Biochemical Oxygen Demand), NH_4^+ - N (ammonium, in nitrogen), and Coliform to evaluate the treatment efficiency of the model.

Research on wastewater treatment using constructed wetlands has shown that increasing the water retention time improves water treatment efficiency [4,7]. Constructed wetlands are used for many purposes: polishing conventionally treated wastewater, holding and treating storm water, treating industrial or agricultural wastewater, and treating acid mine drainage and landfill leachates [8].

2. MATERIALS AND METHODS

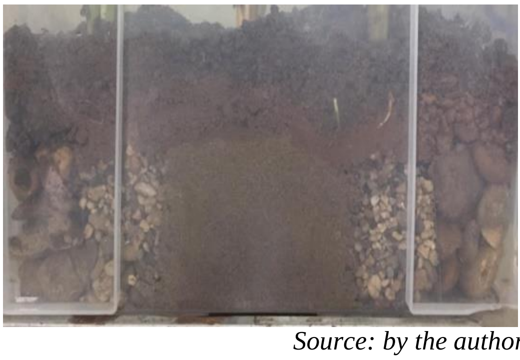
The chosen plant species for experiments in the created wetland were Cannas generalis, which is a common reed and easy to grow both in water and wet land conditions. The reed is a perennial shrub with a rhizome and broad leaves that emerge from the stem in a compact coil. It typically has a tall trunk and may be found in both wet and dry soil conditions. Most cannas plants are immune to pests and are used in constructed wetlands designed for tropical and subtropical wastewater treatment [9,10]. The study found that the seeding plants (see Fig. 1) had an average height ranging from 20 to 25 cm and possessed 2 to 4 seed leaves. The Cannas generalis were planted at a spacing of 10cm, resulting in a density of 23 plants per square meter.

Source:by the authors

Figure 1**.** Image of Free Water Surface wetland with Cannas generalis reeds.

The FWS is operated as horizontal subsurface bed with free water surface flow. The transparent platic was used to make this type of wetland, with the dimensions of 400x600x325 (mm). The subsurface filtration bed used for cultivating hybrid plants (Canna generalis) has a surface area of 0.26 square meters. The wetland received untreated hypothetical wastewater, which is mixed according to the wastewater composition ratio at the rest stop [2]. The research team performed experimental sampling three times: (1), after running the 70-hour model where wastewater from the septic tank seeped into the soil and created a sufficient depth of water layer on the filter site, ensuring a stable flow of wastewater entering and leaving the model; (2), after 10 days; (3), after 20 days. During these samplings, the team evaluated the processing efficiency of various parameters including TSS, BOD5, NH4+ - N, and Coliform. The initial wastewater value (NT1) is assessed during sampling before to starting the model, and is continually supplemented based on the dosing pump, with a calculated velocity of 0.2m/s. Once the model has reached a stable state, proceed to collect samples of the output wastewater from the model on three separate occasions: after 3 days (NT1.3), after 10 days (NT1.10), and after 20 days (NT1.20). These samples should be analyzed for the following indicators: TSS (total suspended solids), BOD_5 (biochemical oxygen demand), NH_4^+ - N (ammonium in nitrogen), and Coliforms. The findings are then compared with QCVN 14:2008/BTNMT (B) standards.

The model tank is constructed from transparent plastic to facilitate viewing of processes taking place within the model and its accompanying equipment. The filter materials include yellow sand, large gravel, small gravel, and topsoil, as shown in Fig. 2. These materials were collected from the wastewater sampling region and are intended to aid in planting and assist plants in adapting to the soil conditions at the construction site.



Source: by the authors

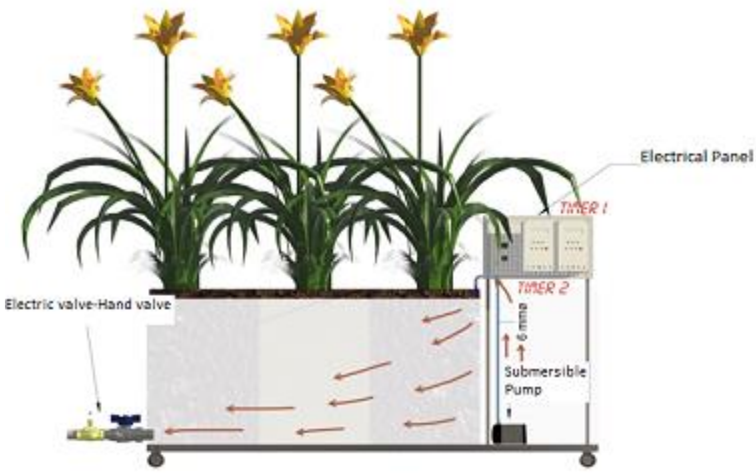
Figure 2. Image of layers of filter materials in the model.

The design capacity of the model is Q = 20 (l/day); The total design water retention time of the model is t = 2.91 days (70 hours); crop density is 0.6-0.7m^2 plants/m^2 model. The specifications of the laboratory scale model are shown in Table 1.

Table 1. Typical dimensions of the calculation model.

	Unit	**Parameter**
Average daily flow	l/ day	20
Filtration site area	m²	0.26
Working height (soil, gravel, stone - materials)	m	0.25
Protection height	m	0.075
Water retention time	h	70
Crop density	m^2/m^2	0,61

Source: the authors



Source:by the authors

Figure 3. Perspective of laboratory-scale FWS model.

The operational principle of the model: The primary mechanisms that govern the model's functioning are situated in the control panel on the right side of the model. Timer No. 1 activates the wastewater pump at a predetermined frequency. When activated, the pump will draw water from the intake wastewater tank through the water distribution hydraulic hose system into the model for 6 minutes, transferring of 20 liters of wastewater. The model surface will distribute water in a horizontal flow, which will then go towards aerobic, anoxic and anaerobic regions. The aerobic zone refers to the region surrounding the roots and rhizomes where oxygen enters the system. The anaerobic zone is located at the bottom of the model, where multiple layers of filter material are present. Between these two zones lies the air deficiency zone. During the retention period of 3 days, microorganisms present in the zones where wastewater and the root system flow will treat the wastewater. Timer No. 2 functions as a device that opens the drain valve to release the treated water in the model, and then promptly closes the valve when all the water has been drained, as shown in Fig. 3.

3. RESULTS AND DISCUSSION

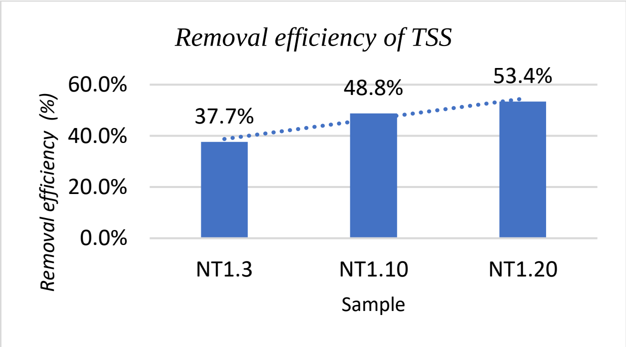
The team implemented of the model and planted of the tree. The authors monitored the growth and development of the plants, as well as the operational functioning of the FWS, for 6 months (September 2023 to March 2024). Afterward, the experiment was initiated using initial hypothetical wastewater to examine the treatment effectiveness of the experimental model over three distinct water retention durations. The inlet wastewater is dark brown color, emits a terrible stench, and contains suspended residue. In contrast, the outlet is clear and devoid of any lingering smell. The BOD_5, Ammonium (NH_4^+ - N), TSS, and Coliform contaminations of wastewater were analyzed before and after treatment, and the results are presented in Table 2.

Table 2. Characteristics of wastewater before and after treatment using the model.

Parameter	NT1	Treated wastewater			QCVN 14 : 2008/BTNMT (B)
		NT1.3	NT1.10	NT1.20	
BOD_5 (mgO_2/l)	180.5	47	43.2	41	50
TSS (mg/l)	152.5	95	78	71	100
NH_4^+ (mg/l)	16.7	9.8	9.1	9.0	10
Total coliform (MPN/100ml)	7,600	4,800	3,700	3,500	5,000

Source: the authors

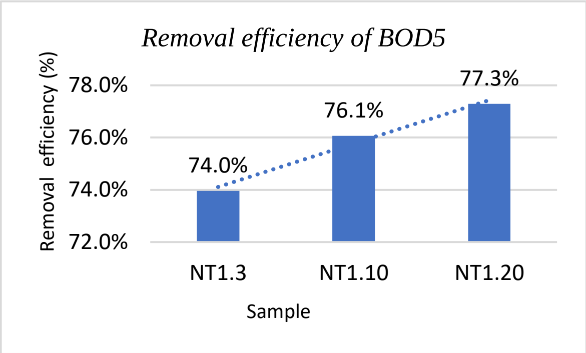
As shown in Fig. 4, the TSS removal efficiency is very high, ranging from 37.7% to 53.4%. primarily due to the filtration and retention of large suspended solids particles by the substrate material layer used for planting plants, as well as the retention of these particles by the roots of plants in the model.



Source: the authors

Figure 4. Removal efficiency of TSS.

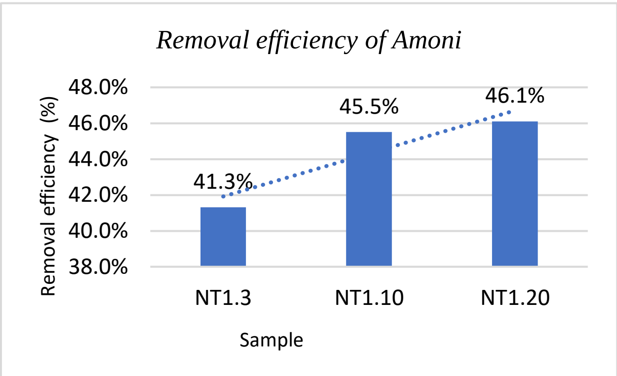
The level of biochemical oxygen demand (BOD_5) presented in Fig. 5 is notably decreased, and the removal efficiency reaches 74.0-77.3%. This is completely justified because most of the large organic particles are captured when they pass through the layer of filter material. Furthermore, microorganisms in the system will break down the dissolved organic matter in the wastewater. Simultaneously, photosynthetic plants transport oxygen to the roots, facilitating the oxygenation required for microbes to degrade organic matter. This process effectively reduces the concentration of organic matter in wastewater and generates minerals. Subsequently, plants absorb these minerals to produce biomass for their growth.



Source: the authors

Figure 5. Removal efficiency of BOD_5.

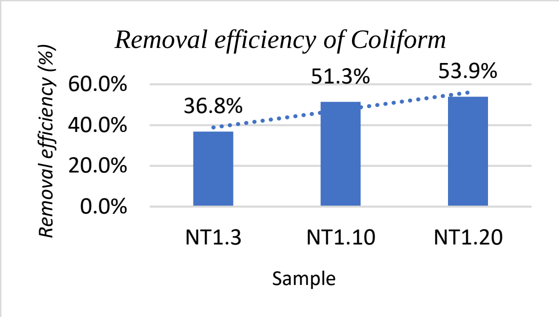
The NH_4^+ - N concentration in wastewater plants take up to enhance biomass should be substantially decreased. Despite achieving a treatment efficiency of 41.3% - 46.1%, the content of NH_4^+ - N in the output wastewater exceeds the limits set by QCVN 14:2008/BTNMT (B) standard, as shown in Fig. 6.



Source: the authors

Figure 6. Removal efficiency of Amoni.

The presence of coliforms in wastewater is greatly diminished due to two factors: the entrapment of coliforms by the biofilm layer in the wastewater, and the competition with microorganisms residing in the vicinity of plant roots. The processing efficiency ranges from 36.8% to 53.9%. The concentration after treatment complies with the QCVN 14:2008/BTNMT(B) standard, as shown in Fig. 7.



Source: the authors

Figure 7. Removal efficiency of Coliform.

Table 3. Efficiency of FWS constructed wetland for wastewater treatment.

Samples	**Removal efficiency (%)**			
	TSS	**BOD_5**	**Coliform**	**NH_4^+**
NT1	37.7	74.0	36.8	41.3
NT1.10	48.8	76.1	51.3	45.5
NT1.20	53.4	77.3	53.9	46.1

Source: the authors

Throughout the 6-month trial and monitoring period (from September 2023 to March 2024), the study team discovered several characteristics associated with cultivating canna hybrid plants (Canna generalis) that significantly impact the model's removal efficiencies. The plant exhibits various signs, including brown spots on the tips and edges of the leaves, yellowing of the foliage, wilting, and the presence of little white spots on the underside of the leaves... These problems primarily arise from root waterlogging, which hinders the plant's ability to absorb water and nutrients, as well as root rot and aphids. Therefore, it is imperative to conduct further investigations on climatic conditions, temperature, and light to ensure consistent plant growth. Currently, the team is persistently observing the tree's growth pattern throughout the different seasons of year to evaluate, in order to evaluate the model's adaptability in practical use.

The design filter site model has a capacity of 20 liters per day. As shown in the table 2, the model has a total water retention time of 70 hours. After pretreatment through ST, the pollutant content is as follows: TSS is 152.5 milligrams per liter, BOD_5 is 180.5 milligrams per liter, Ammonium (NH_4^+ - N) is 16.7 milligrams per liter, and Coliforms are 7,600 MPN per 100 milliliters. The model tank achieves treatment efficiencies of 37.7% for TSS, 74.0% for BOD_5, 41.3% for Ammonium, and 36.8% for Coliforms with a water retention time of 70 hours (~3 days). The high processing performance of the ST system ensures that household wastewater meets the standards set by QCVN 14:2008/BTNMT (B) after treatment. Nevertheless, the research team performed surveillance on the operational mode of the model. It monitored the treated wastewater under water retention circumstances in the model tank for 10 days (NT1.10) and 20 days (NT1.20). The findings indicated a further decline in the concentration of contaminants compared to the NT1.3 sample, accompanied by increased removal efficiency. As shown in the table 3, TSS, BOD5, and NH4+ - N removal efficiency for the NT1.10 and NT1.20 models is 48.8-53.4%, 76.1-77.3%, and 45.5-46.1%, respectively. The efficiency of coliform digestion remains generally constant at a rate of 51.3-53.9%. The efficiency of treating contaminants in domestic wastewater following sewage treatment is significantly high, resulting in the output water meeting the standards outlined in QCVN 14:2008/BTNMT (B) and being suitable for reuse. [11].

Based on the outcomes of wastewater treatment facilities and the data shown in Table 3, it can be concluded that the treatment efficiency of the flood filter site model is comparable, albeit not significantly different, from both actual facilities and previous research. Several investigations have demonstrated that BOD5, TSS, and NH4+ -N exhibit an average removal effectiveness of 81%, 85%, and 93% respectively, in the case of FWS [4,12,13]. A study conducted at NMAM Institute of Technology (NMAMIT) in Udupi district, India, revealed that the using of banana blossoms in wastewater treatment resulted in an efficiency of 51.9% for nitrate treatment and 8.9% for phosphate treatment [14,15,16]. Notably, the domestic wastewater used in this research has yet to undergo pretreatment with septic tanks. This showcases the efficiency of the laboratory-scale FWS model in the purification of household wastewater.

4. CONCLUSION

Experimental evidence demonstrates that a minimum duration of 2.91 days is required to remediate water contaminants, effectively yielding a commendable efficiency level. The post-septic tank treatment of wastewater shall be conducted at designated plantation filter sites located at a considerable distance from residential areas. This treatment ensures the quality of the treated water sources, meeting the standards set by QCVN 14: 2008 / BTNMT (B). Using the flood filter site model at small and medium-sized rest stops far from residential areas, is highly advantageous and essential when compared to directly releasing of domestic wastewater into the environment after passing through a septic tank. This treatment model not only provides significant environmental benefits but also enhances the area’s aesthetic appeal by creating green landscapes.

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