

Assessment Efficiency of Vermifiltration in Municipal Wastewater Treatment: A Pilot Study

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Abstract

Aim: Nowadays, most developing countries face the challenge of ever-increasing municipal sewage in rural areas. In this respect, many countries cannot afford the cost of establishing a wastewater treatment plant. Therefore, this study aims to obtain executive information and evaluate the efficiency of vermilter (VF) in domestic wastewater treatment. **Methods:** This study investigates the performance of a pilot-scale vermifilter system containing *Eisenia fetida* earthworms for sanitary wastewater treatment. For this purpose, a pilot-scale vermifilter was installed to ascertain the variation of pH, biological oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solid (TDS), NO₃-N, NH₃-N, TN, PO₄³⁻ and total phosphorus (TP) in an incubation period of 120 days. In addition, a conventional geofilter without earthworm was used as the experimental control. The process includes using two small cylindrical plastic reactors with a depth of 62.5 cm and a capacity of 80 L. **Results:** The vermifiltration (VF) caused a significant decrease in the levels of BOD₅ (92.5%), COD (77.1%), TSS (88.8%), TDS (70%), NH₃-N (95.11%), TN (52%), PO₄³⁻ (77.1%), and TP (69.86%). Meanwhile, the removal efficiencies for the above parameters in the control reactor were 54.94%, 67.5%, 70.4%, 53.37%, 42%, 77.3%, 72.65%, and 62.17%, respectively. **Conclusion:** Vermifilter is one of the feasible methods for wastewater treatment. Therefore, VF technology can be considered an environmentally friendly method for wastewater treatment.

Keywords: Biofilter, *Eisenia fetida*, municipal wastewater, vermifiltration

INTRODUCTION

The unrestrained population growth, urbanization, and intense industrial activities use enormous amounts of freshwater and discharge huge amounts of wastewater containing hazardous contaminants such as organics, nutrients, and pathogens.^[1,2] In 2010, the World Health Organization recognized access to drinking water and sanitation as a human right. However, in 2020, 45% of the sewage generated in the world was still discharged without safe treatment.^[3] Furthermore, research has shown that sanitation coverage is often much lower in rural areas than in urban areas. The lack of adequate sanitation services can lead to environmental pollution, causing water quality deterioration, biodiversity loss, and changes in an ecosystem's structure and function.^[4] About 25% of urban inhabitants of developing countries lack access to sanitation services, whereas the figure reaches up to 82% for rural populations in developing countries.^[5] vermifiltration (VF) is an economically efficient wastewater treatment alternative

using earthworms to increase and diversify the microbial communities residing in soil-based biofilters.^[6] Later, wastewater treatment through earthworm-assisted VF technology emerged as a successful technique in treating domestic wastewater, industrial wastewater such as herbal pharmaceutical wastewater, gelatine wastewater, and dairy wastewater.^[7] Treatment systems with relatively low operational and energy are preferred for municipal wastewater treatment.^[8] One of the feasible and promising solutions to deal with the crisis of water shortage and pollution of available

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water in developing countries is establishing treatment systems with low operational and maintenance costs that also meet the environmental criteria for sewerage discharge.^[9] VF is a natural, inexpensive, and effective technology for treating municipal wastewater.^[10] This technology was first supported by Professor Jose Thoa at the University of Chile in 1992. Samal *et al.* also reported that the earthworms act as a biofilter. this technique is used as an organic method to treat polluted water.^[11,12] In the present study, we investigated the performance of sanitary wastewater treatment. In addition, the removal efficiency of biological oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solid (TDS), NO₃⁻-N, NH₃-N, TN, PO₄³⁻, and total phosphorus (TP) parameters is ascertained using the VF process for sanitary wastewater treatment in an incubation period of 120 days.

MATERIALS AND METHODS

Reactor setup and operation

Successful design and operation of vermifilter are essential to achieve sustainable treatment. This function includes hydraulic retention time, hydraulic loading rate, worm selection, materials used as media in VF, the height of the vermifilter, and earthworm density. In this research, the efficiency of

purification urban wastewater was measured in two ways on a pilot scale: one vermifiltration (VF): Reactor inoculated with different substrates and another geofilter (GF): A control reactor (VF reactor without earthworm). The wastewater used in the study was obtained from the Shahrekord wastewater treatment plant, operated with a conventional activated sludge process.

Two plastic cylindrical vermifilter reactors with a working volume of 80 L (internal diameter: 37 cm and height: 52.94 cm) were operated. Figure 1 shows an overview of the vermifilter pilot used in this research. From top to bottom, the materials used to make vermifilter are as follows: 25 cm of a thick soil bed mixed with small rocks and gravel in that worms are present, 5 cm of dry tree leaves as a natural adsorbent to remove nutrients from sewage and mineralization of organics in wastewater, 5 cm of sawdust as adsorbent to absorb various types of inorganic waste pollutants, 5 cm of a thick layer of small rocks and sand with a diameter of 5–7 cm as a filtration unit, and 12.7 cm of stone large plants with a diameter of 10–15 cm to create a type of air chamber system and water storage at the base of the system.^[9,13]

After acclimating the earthworms with the soil substrate, the VF substrate was continuously fed with sewage at a hydraulic

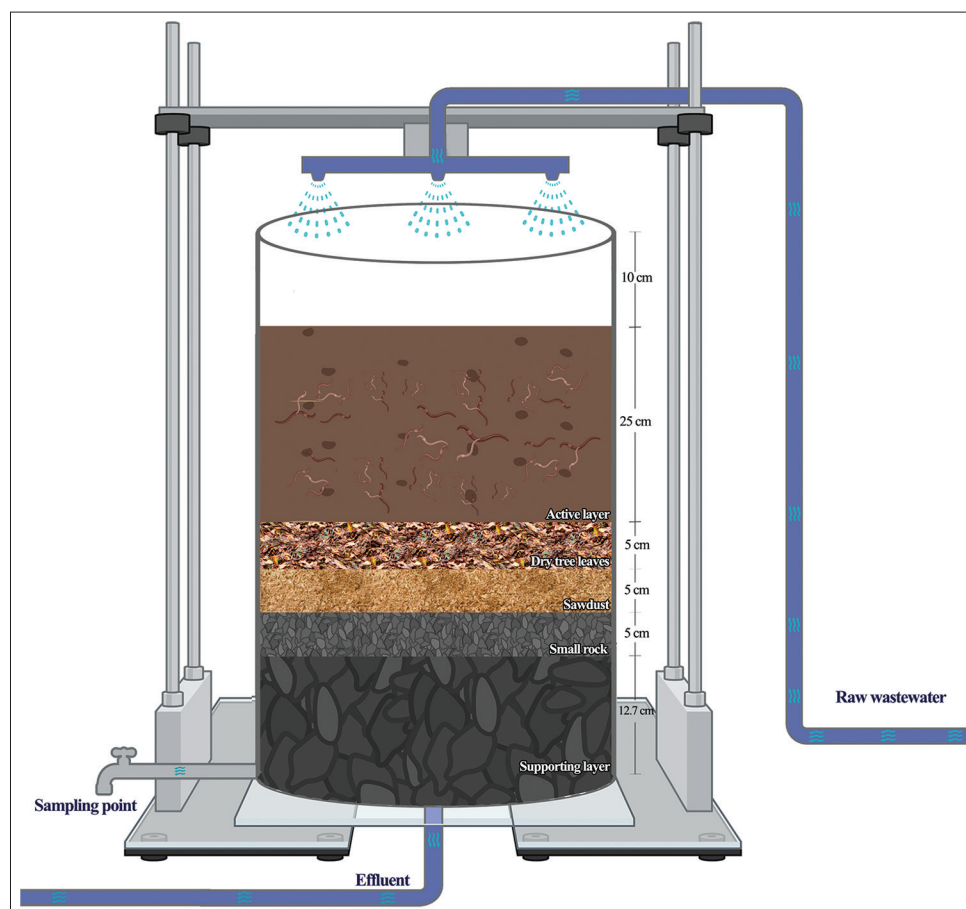


Figure 1: Layers of the vermifiltration system

loading rate of $1 \text{ m}^3 / \text{m}^2 \cdot \text{d}$ for 4 months. To prevent clogging of the raw sewage system, it was transferred to the pilot by a peristaltic pump after passing through the preliminary treatment unit (garbage and grain collection). Following the construction and start-up of the pilot in the treatment plant, sampling was done for 4 months weekly from three points (1 – pilot inlet, 2 – VF outlet, and 3 – control filter

outlet). It is of note that the sampling was performed after 2 weeks of continuous operation of the system and adaptation of the earthworms to the pilot environment. Table 1 shows the physical and chemical properties of the wastewater fed to the VF reactors. The acclimation process of *Eisenia fetida* diesel in VF with different proportions of sludge (amendment), vermicomposting material (bulking agent), and contaminated soil was performed in the earlier stage.

Table 1: The physical and chemical characteristics of wastewater fed into vermifiltration systems

Parameter	Unit	Concentration
BOD ₅	mg/L	167.2
COD	mg/L	331
TSS	mg/L	343.33
TDS	mg/L	504
NO ₃ -N	mg/L	23–30.5
NH ₃ -N	mg/L	15.3–60.2
TN	mg/L	30.4–100
PO ₄ ³⁻	mg/L	2.52
TP	mg/L	3.5–5.31
pH	-	6.94

TP: Total phosphorus, BOD: Biological oxygen demand, COD: Chemical oxygen demand, TSS: Total suspended solids, TDS: Total dissolved solid

Table 2: Summary of vermifilter design and operating parameters

Parameter	Value	Unit
HLR	1	$\text{m}^3/\text{m}^2 \cdot \text{d}$
VF volume	80	m^3
VF area	0.106	m^2
VF height	62.7	cm
VF flow	0.96	m^3/d
Temperature	21	$^{\circ}\text{C}$
Earthworm density	10,000	Worm/ m^3
Active layer		Layer 5
Active layer height	25	cm
Species		<i>Eisenia fetida</i>
C/N ratio	17.2	

HLR: Hydraulic loading rate, VF: Vermifilter

Table 2 provides a summary of the design and operating parameters of VF.

After acclimatization, the sampling was performed weekly from three points (pilot inlet and outlet effluent) to measure various physical and chemical parameters. PH, TSS, TDS, BOD₅, COD NO₃⁻-N, NH₃-N, TN, PO₄³⁻, and TP were measured as per the procedure outlined by the standard method for water and wastewater examination.^[14,15]

The removal efficiency (R) in different reactors was calculated and estimated by the following equation:

$$R(\%) = \frac{C_i - C_o}{C_i} \times 100 \tag{1}$$

Statistical analysis

A statistical paired *t*-test was performed to analyze the process efficiency between different reactors. A one-way analysis of variance was also performed to measure the difference between cycles of each physicochemical parameter of wastewater. Data analysis was performed by SPSS18 software (IBM company, University of Chicago), and graphs were drawn using Excel 2007.

RESULTS

pH changes

Figure 2 illustrates the pH variations during the treatment period in two pilots: VF and GF. The average pH of raw wastewater was 6.94. Besides, the average pH for effluents from VF and control was 7.21 to 7.22, respectively.

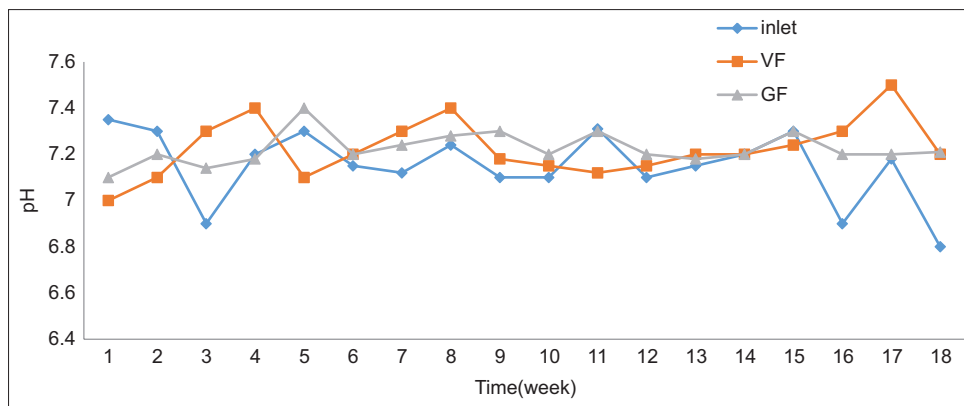


Figure 2: The variation of pH in vermifilter (VF) and geofilter (GF) systems during the treatment period.

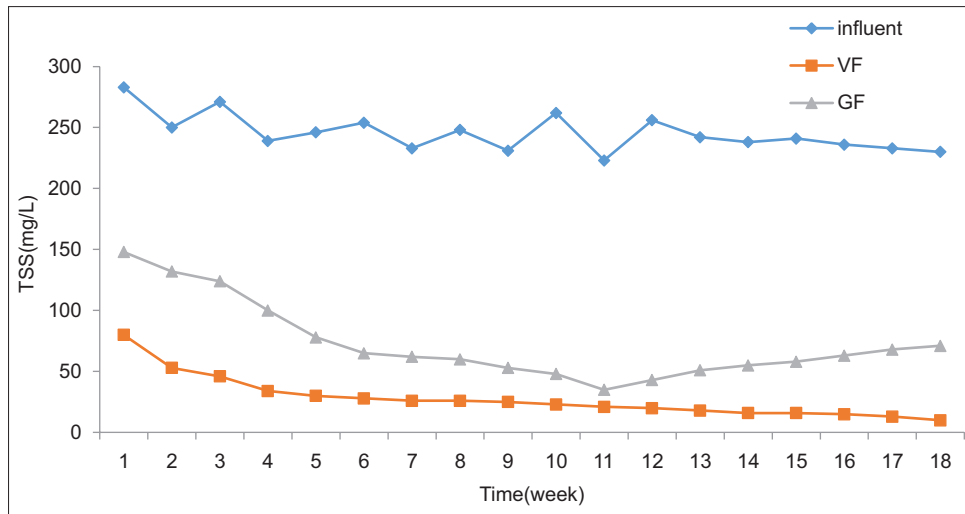


Figure 3: The total suspended solids (TSS) variations in vermifilter (VF) and geofilter (GF) systems during the treatment period.

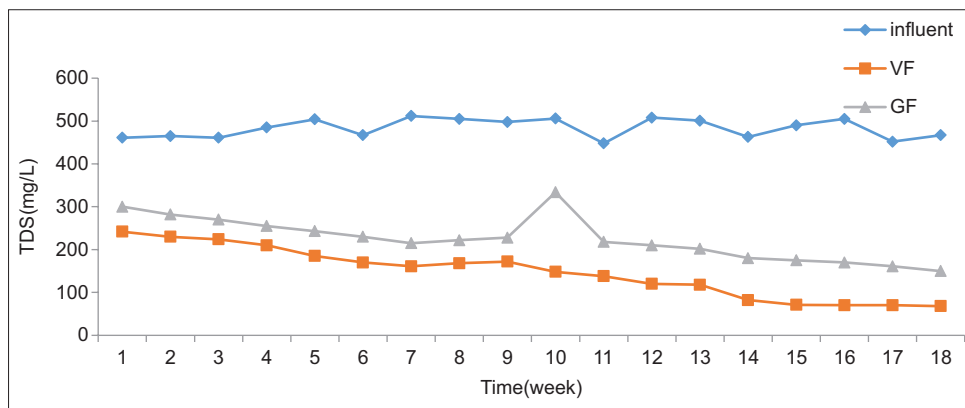


Figure 4: The total dissolved solid (TDS) variations in vermifilter (VF) and geofilter (GF) systems during the treatment period.

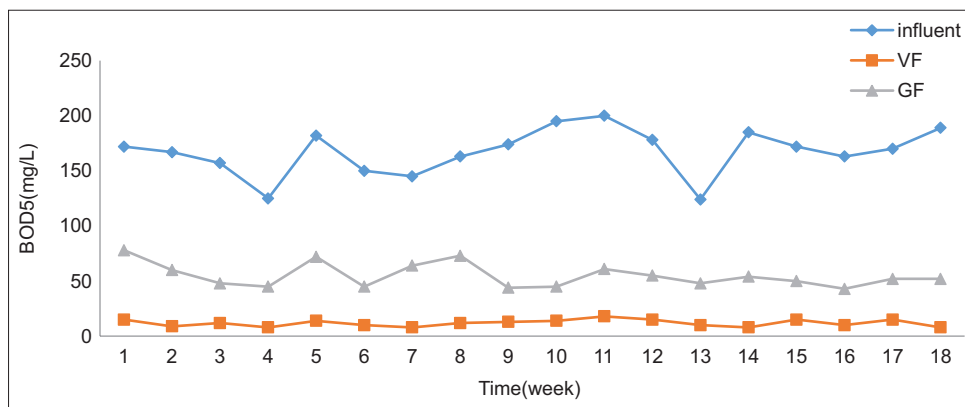


Figure 5: The biological oxygen demand (BOD5) variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

Total suspended solids and total dissolved solid removal

As can be seen from Figures 3 and 4, earthworms can significantly remove TSS and TDS from wastewater in VF and GF systems.

Biological oxygen demand and chemical oxygen demand removal

The BOD₅ removal in the VF reactor was significantly higher

than that of the GF reactor. Figure 5 compares the efficiency of VF and GF filter systems in BOD₅ removal. As shown in Figure 6, both GF and VF can purify the COD load by 75%–65%, respectively.

NO₃⁻-N, NH₃-N, and TN removal

Figures 7-9 compare the change in the values of NO₃⁻-N,

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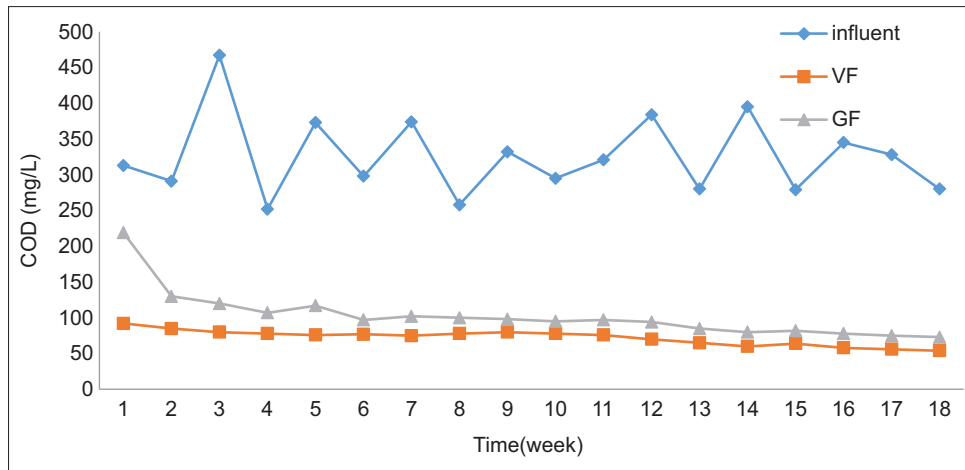


Figure 6: The chemical oxygen demand (COD) variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

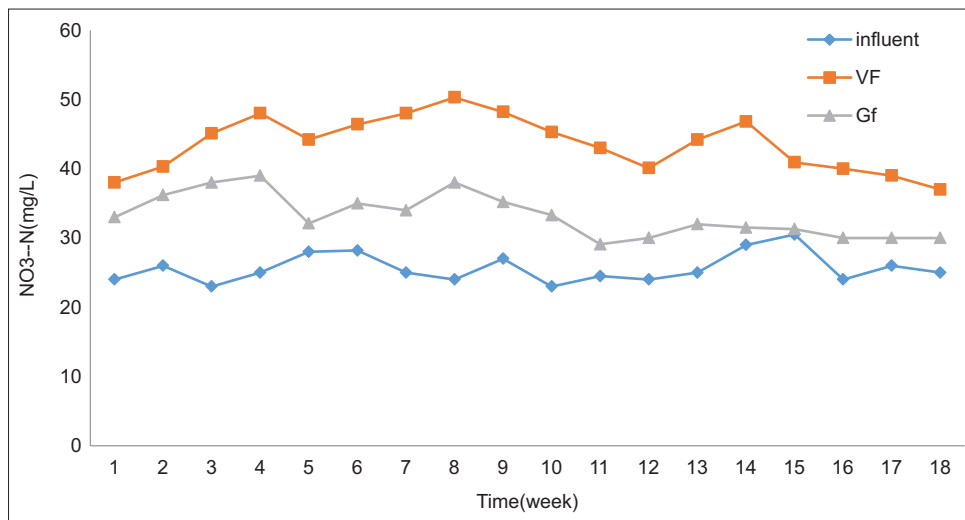


Figure 7: The NO₃-N variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

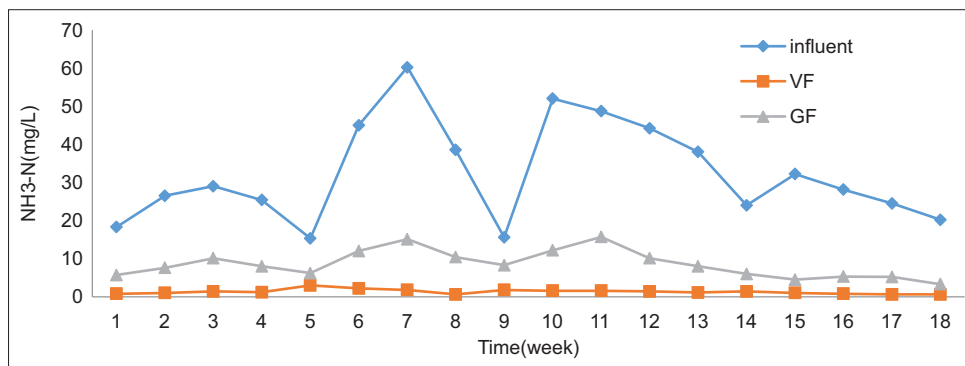


Figure 8: The NH₃-N variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

NH₃-N, and TN in the VF system and the GF during the treatment period, respectively. As can be seen, the average NO₃⁻-N in the raw sewage entering the pilot is about 25.6 mg/L. After the purification process, the amount of NO₃⁻-N in VF reached 43.6 mg/L, whereas it reached 33.04 mg/L in the control filter. The average amount of NH₃-N

in the incoming raw sewage was 32.53 mg/L, whereas it reached 1.32 mg/L in the VF effluent and 8.27 mg/L in the control filter effluent. The average removal of NH₃-N in the VF system and the control filter was about 95.11% and 73.77%, respectively. The average removal of TN in the VF and GF systems was 52% and 42%, respectively.

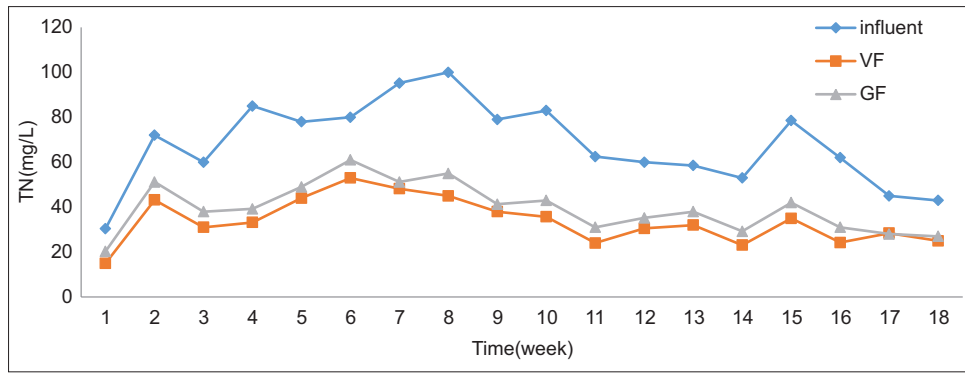


Figure 9: The TN variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

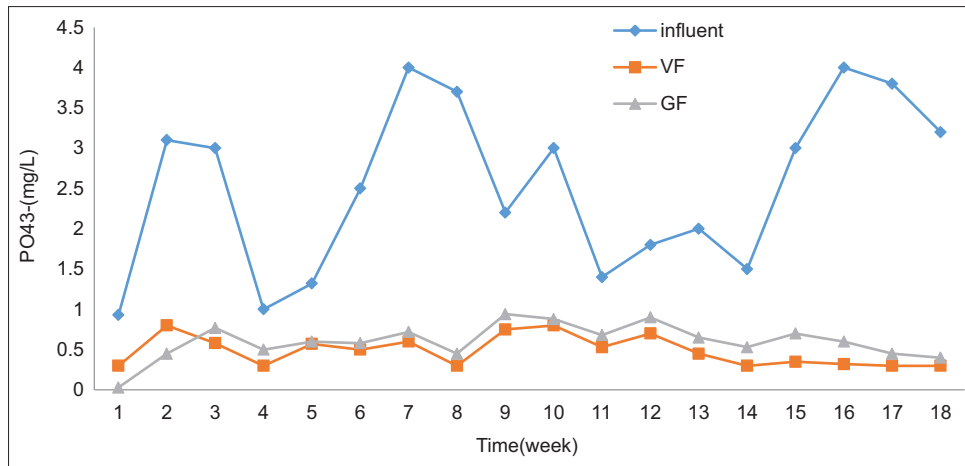


Figure 10: The PO₄³⁻ variation in vermifilter (VF) and geofilter (GF) systems during the treatment period.

PO₄³⁻ – and total phosphorus removal

Figures 10 and 11 indicate the amount of phosphate (PO₄³⁻) and TP removal in the two VF and GF systems during the treatment period, respectively. The average amount of PO₄³⁻ in the raw wastewater entering the pilot was about 2.52 mg/L. The average PO₄³⁻ in the VF outlet effluent and control filter was 0.48 and 0.6 mg/L, respectively. The average PO₄³⁻ removal in the VF system and control filter is 77.1% and 72.65%, respectively. In addition, the average concentration of TP in the raw wastewater entering the pilot is about 17.21 mg/L. After VF, the average concentration of TP was 4.64 in the VF system and 6.51 mg/L in the control filter. Moreover, TP concentration in the VF effluent decreased more than in the control filter.

DISCUSSION

pH

In VF and during the purification period, the pH was initially increased but reached a constant level in the neutral range. This finding confirms the inherent ability of earthworms to mineralize organic compounds and convert them to CO₂ and other mineral salts.^[16] The internal adjustment of pH by its increase can be attributed to earthworms' rapid neutralization of the organic part of the wastewater.^[11,13]

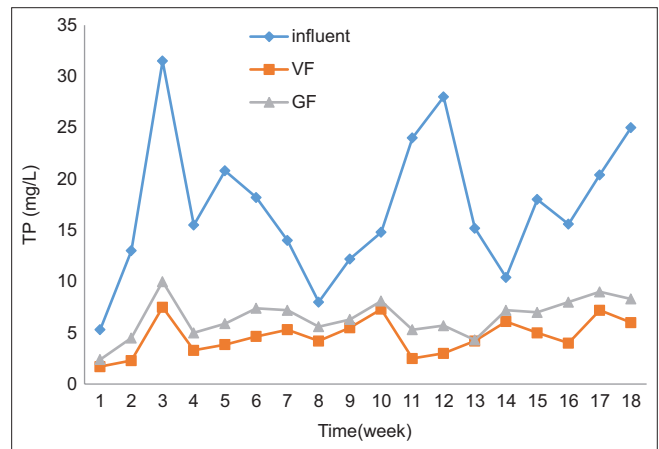


Figure 11: The total phosphorus (TP) variation in vermifilter (VF) and geofilter systems (GF) during the treatment period.

Total suspended solids and total dissolved solid removal mechanism in VF and geofilter

The difference between the two systems is due to differences in biological components and their ability to operate in both reactors. Suspended solids are trapped on the first layer in the filtration system. The SS accumulated on the filter bed serves

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as “sludge” in a normal biofilter, blocks the system, and stops the system from proper functions.^[17] Li *et al.* reported the removal rate of TSS in a study titled using VF in pilot-scale rural wastewater treatment at 89.1%.^[17-20] Wang L *et al.* and Taylor M *et al.* (2011) reported the removal rate of TSS and TDS in the range of 90%–92% and 90%–95%, respectively. These authors attributed the removal of TSS to its continuous consumption by earthworms.^[21,22] The results of the present study confirm the findings of other researchers who claimed the importance of earthworms in the VF system.

Chemical oxygen demand and biological oxygen demand removal mechanism

The higher BOD₅ removal in VF is attributed to the activity of earthworms and related microorganisms.^[8] Furthermore, more removal of BOD₅ in VF is attributed to the symbiotic activity of earthworms and aerobic microbes that decompose organic matter.^[18,23,24] Li *et al.* (2009) reported a BOD₅ removal rate of 96% in a continuous on-site treatment system.^[25] The findings showed that both GF and VF can purify the COD load by 75%–65%, respectively. These results could be due to earthworms and microorganisms’ physical, chemical, and biological processes and synergistic effects. Among these effects are the uptake of particles by small organisms, colloidal organisms, and organic molecules, the reduction-oxidation of organic matter, and the activity of earthworms.^[21]

Mechanism of removal of nitrogen compounds

Nitrate is an important indicator of water pollution, with its high concentration in freshwater leading to the formation of eutrophication.^[26] Bhargava *et al.* found out that the amount of NO₃⁻-N in wastewater increases due to the activity of earthworms and the production of ammonia and other forms of nitrogen. The increase in nitrate nitrogen is due to the transformation of organic matter of wastewater through biological processes. In VF, nitrate concentration increases at the beginning, but it decreases and remains almost changeless at the end of the operation.^[20,27] Through biological nitrification by aerobic autotrophic bacteria, ammonia is oxidized to nitrite and nitrate.^[13] Studying the nitrogen removal mechanism, Li *et al.* reported that the bodies of earthworms and microorganisms may consume part of the NH₃-N. The remaining part will be removed due to forming N₂, NH₃, and Nox through nitrification, denitrification, and ammonification. Earthworms secrete polysaccharide, proteins, and other nitrogenous compounds. They mineralize nitrogen to make it available as nutrients for plants.^[28,29] Samal K *et al.* reported 63% and 70.5% removal of TN and NH₃ in synthetic wastewater, respectively. The nitrogen removal from wastewater is mainly because of nitrifiers and denitrifying bacteria in earthworms.^[28]

Mechanism of removal of phosphorus compounds

It is clear that the PO₄³⁻ removal process is slow and linear in GF, but the PO₄³⁻ removal process is faster in the VF reactor. Ligand exchange reactions and physical adsorption or adsorption sites quickly remove phosphorus from the soil solution.^[13,28,29] The phosphorus removal rate is higher in VF

because phosphorus particles are trapped in VF and converted into soluble phosphorus through the biological activity of worms. Bhargava *et al.* reported a significant increase in TP in vermifilter effluent in domestic wastewater treatment. This increase may be due to worms’ microbial and enzymatic activity.^[27]

CONCLUSION

The current work provides an opportunity to explore the efficiency of a VF system for the treatment of municipal wastewater. The present study’s experimental data revealed that the VF system is more efficient than GF in removing BOD₅, COD, TSS, TDS, NO₃⁻-N, NH₃-N, TN, PO₄³⁻, and TP. This is a notable advantage of VF. Although the results from the present study clearly indicated that the VF is an appropriate technique with high performance for hospital wastewater, further detailed studies are still required

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Ethics code

IR.MUQ.REC.1399.259.

Conflicts of interest

There are no conflicts of interest.

Author contributions

Morteza Shanbedi: Collecting data; Ahmad Reza Yari: Study concept and design; Mehdi Asadi: Analysis and interpretation of data; Mohammad Fahiminia: Drafting of the manuscript; Davood Jalili Naghan: Statistical Analysis;

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