JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 25(12), 124–135
https://doi.org/10.12911/22998993/194007
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.09.15
Accepted: 2024.10.20
Published: 2024.11.01

Phytoremediation of Landfill Leachate Using *Chlorophytum comosum*, *Echinodorus palaefolius*, and *Hippochaetes lymenalis*

Rhenny Ratnawati[1*], Indah Nurhayati[1], Imam Nur Rohim[1], Vivin Adriani[2]

[1] Program Study of Environmental Engineering, Faculty of Engineering, Universitas PGRI Adi Buana Surabaya, Dukuh Menanggal XII/4 Surabaya, 60234, Indonesia

[2] Program Study of Biology, Faculty of Science and Technology, Universitas PGRI Adi Buana Surabaya, Dukuh Menanggal XII/4 Surabaya, 60234, Indonesia

* Corresponding author's e-mail: ratnawati@unipasby.ac.id

ABSTRACT

Phytoremediation is an alternative technology for treating leachate by utilizing plants. The objective of this study was to examine the concentrations of total suspended solid (TSS), total nitrogen (TN), and cadmium (Cd) in leachate through the phytoremediation process using *Chlorophytum comosum*, *Echinodorus palaefolius*, and *Hippochaetes lymenalis*. The research was conducted on a laboratory scale with a batch system. The leachate was sourced from the Ngipik Landfill, Gresik, East Java, Indonesia, and was collected from the inlet of the Ngipik Landfill Leachate Treatment Unit. Acclimatization was carried out for 7 days. A range finding test (RFT) was conducted by varying the concentration composition of the leachate compared to tap water, with the planting medium being 25% leachate: 75% tap water, 50% leachate: 50% tap water, 50% leachate: 75% tap water, and 100% leachate: 0% tap water (v/v). The plants used in each reactor weighed 1 kg. The reactors used for the phytoremediation process were plastic boxes with dimensions of 51×32×31 cm. The planting medium consisted of gravel-sized 10–20 mm, with a thickness of 7 cm, and soil with a thickness of 7 cm. This research showed that the average final TSS concentration of the leachate was 25.50 ± 44.37 mg/L. The average TSS reduction efficiency reached 94.90 ± 8.87%. The average final TN concentration of the leachate was 409.42 ± 139.19 mg/L, with an average TN reduction efficiency of 89.73 ± 4.62%. The average Cd concentration in the leachate was 0.0012 ± 0.0013 mg/L, with an average Cd concentration reduction efficiency of 92.30 ± 8.48%. The final TSS and Cd concentrations met the leachate quality standards, with values of 100 mg/L and 0.1000 mg/L, respectively. However, the final TN concentration did not meet the leachate quality standards, as the final TN concentration in the leachate was 60 mg/L.

Keywords: *Chlorophytum comosum*, *Echinodorus palaefolius*, *Hippochaetes lymenalis*, phytoremediation, landfill, leachate.

INTRODUCTION

Leachate, as a result of the waste decomposition process, contains high levels of organic and inorganic substances (1, 2). Leachate is a liquid contaminated with chemicals and heavy metals that are harmful to the environment (3, 4). When leachate is discharged into water bodies without treatment, it can lead to pollution of surface water, groundwater, and soil, and cause unpleasant odors (5, 6). Therefore, alternative leachate treatment technologies are needed as part of water, soil, and air conservation efforts.

Phytoremediation is one such alternative leachate treatment technology that utilizes plants. This method can reduce, stabilize, and absorb pollutants present in leachate (7, 8). Phytoremediation uses the ability of certain plants to accumulate pollutants based on the characteristics of the plants used (9). Phytoremediation has been reported to effectively reduce pollutants with high removal efficiency, relatively low operational and maintenance costs, and is more environmentally friendly. Previous studies have demonstrated the successful use of phytoremediation in treating leachate (10–12).

The phytoremediation process is divided into five stages: phytodegradation, phytoextraction, phytovolatilization, phytofiltration, and phytostabilization (13). Phytodegradation occurs when plants absorb, store, degrade, and transform organic materials into harmless by-products through plant metabolism (14). This process takes place in the roots, stems, and leaves of plants with the help of enzymes released by the plants themselves. Phytoextraction is the process where contaminants are transferred into plant tissues (15). These contaminants can be removed by harvesting hyperaccumulating plants (16). Phytovolatilization refers to the volatilization of contaminants by leaves, where toxic substances are transformed into less toxic forms (17). Phytofiltration involves the accumulation of contaminants in the rhizosphere or plant roots (18). Phytostabilization is the process where plants attract specific contaminants to the roots, which cannot be transferred to other parts of the plant (19). These contaminants become tightly attached to the roots, preventing them from being transported through the surrounding medium.

Plants that have been successfully used for leachate phytoremediation include *C. comosum, E. palaefolius,* and *H. lymenalis* (20, 21). The type of plant used affects the absorption of specific compounds from pollutants (22). Hyperaccumulator plants can survive in conditions with high levels of pollutants and absorb these pollutants into their metabolism (23). The root zone is also a key focus in phytoremediation. Roots can absorb contaminants and either store or metabolize them within the plant tissues (18). The degradation of contaminants in the planting medium by plant enzymes secreted by the roots is one of the mechanisms in the phytoremediation process (22). The objective of this study was to examine the concentrations of TSS, TN, and Cd in leachate through the phytoremediation process using *C. comosum, E. palaefolius*, and *H. lymenalis*.

MATERIAL AND METHODS

Characteristics of landfill leachate

The leachate used in this study was sourced from Ngipik Landfill, Gresik, East Java, Indonesia. It was collected from the inlet of the Ngipik Landfill Leachate Treatment Unit. The initial characteristics of the leachate are shown in Table 1. The initial concentrations of TSS, total nitrogen (TN), and cadmium in the Ngipik Landfill leachate were 500 mg/L, 4,955.92 mg/L, and 0.02 mg/L, respectively. The leachate water quality standards required by (24) for TSS, total nitrogen, and cadmium are 100 mg/L, 60 mg/L, and 0.1 mg/L, respectively. Thus, the initial TSS and TN levels in Ngipik Landfill exceed the required standards, while the cadmium level complies with the standard.

Acclimatization

The purpose of acclimatization is to allow the plants *C. comosum, E. palaefolius, and H. lymenalis* to adapt to their new environmental conditions (25). Acclimatization was carried out by growing the plants in clean water without the addition of leachate for 7 days. The plants used for the study were healthy and free from death (9). New shoots that grew on *C. comosum, E. palaefolius,* and *H. lymenalis* are shown in Figure 1.

Range finding test

The objective of the range finding test (RFT) is to determine the tolerance level of plants in absorbing pollutants from leachate at specific

Table 1. Characteristics of landfill leachate

Parameter	Unit	Result	Standard*
pH value	-	8	6–9
Temperature	°C	30	-
BOD concentration	mg/L	585	150
COD concentration	mg/L	3.593	300
TSS concentration	mg/L	500	100
Total N concentration	mg/L	4,955.92	60
Mercury concentration	mg/L	1.39	0.005
Cadmium concentration	mg/L	0.02	0.1

Note: * (24).

a. *C. comosum* b. *E. palaefolius* c. *H. Lymenalis*

Figure 1. New shoot growth

concentrations (26). The variation in leachate concentration compared to tap water in the planting medium was as follows: 25% leachate: 75% tap water, 50% leachate: 50% tap water, 75% leachate: 25% tap water, and 100% leachate: 0% tap water (v/v). The RFT was conducted over 9 days, during which plant morphology was observed. The concentration of pollutants in the leachate that did not cause any adverse effects on the plants was selected for the phytoremediation test. The RFT results showed that all three plants were able to adapt to a concentration of 75% leachate: 25% tap water.

Phytoremediation of landfill leachate

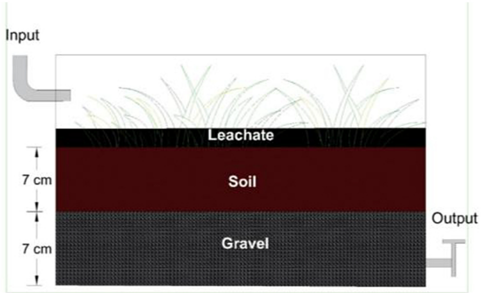
The research was conducted on a laboratory scale using a batch system to test the ability of *C. comosum, E. palaefolius*, and *H. lymenalis* to remediate concentration of TSS, TN, and Cd in leachate. The planting medium composition was based on the RFT results, where the ratio of leachate to tap water was 75%: 25%. Each reactor contained plants weighing 1 kg. The reactors used for the phytoremediation process were plastic boxes with dimensions of 51×32×31 cm (Figure 2). The planting medium consisted of gravel-sized 10–20 mm with a thickness of 7 cm, and soil with a thickness of 7 cm. The volume of leachate in each reactor was 15 liters. Leachate samples were collected every 3 days over the 9-day research period. The parameters analyzed included pH, temperature, TSS concentration, TN, and Cd using (27). The pH values were measured using a pH meter, temperature was recorded with a thermometer, TSS was determined through gravimetric testing, TN was measured using the Kjeldahl method, and concentrations of Cd were analyzed using atomic absorption spectroscopy.

RESULTS AND DISCUSSION

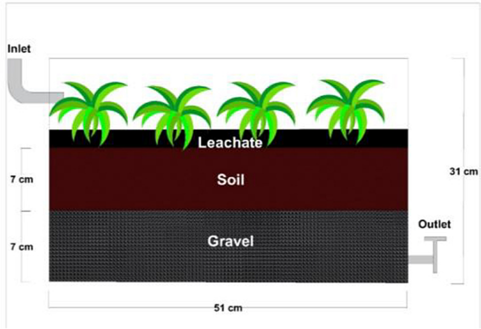
The decrease of TSS concentration in landfill leachate

The initial TSS concentration in all four reactors was 500 mg/L. A decrease in TSS concentration was observed across all phytoremediation reactors (Figure 3). In the *C. Comosum* reactor, the TSS level sharply declined by day 3 of the study to 80 mg/L. Similarly, a significant decrease was observed in the H. lymenalis reactor, where TSS dropped to 44 mg/L by day 3. A different trend was seen in the E. palaefolius reactor, where the sharpest TSS decrease occurred on day 6, reaching 12 mg/L. The TSS levels continued to decline until the end of the study across all reactors. The final TSS concentration in the four reactors averaged 25.50 ± 44.37 mg/L. The final TSS value in the leachate met the leachate quality standards as required by (24), with a limit of 100 mg/L.

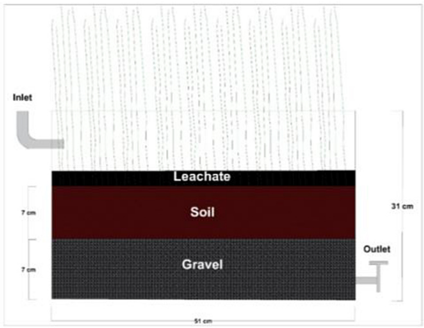
The reduction in TSS levels in the leachate is primarily due to the role of plants in supporting the flow rate during the phytoremediation process, facilitating the sedimentation of solids. Filtration occurs at the plant roots, which act as a filter for the leachate, reducing TSS levels by capturing solid particles from the leachate (28). The roots form a natural filter, retaining all solid particles present in the leachate. Besides filtration, sedimentation also contributes to the reduction of TSS, requiring sufficient retention time for the organic material to settle. Additionally,



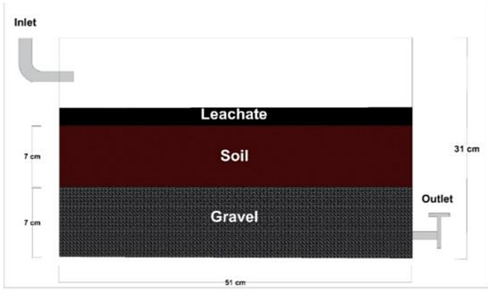
a. *C. comosum*



b. *E. palaefolius*



c. *H. lymenalis*



d. control

Figure 2. Phytoremediation reactor of landfill leachate

the gravel and soil used in the phytoremediation reactors further enhanced the reduction of TSS levels. The planting medium in the reactors acts as a filtration of TSS levels in leachate. (29) concluded that the rhizosphere is the most important area during the phytoremediation process. The rhizosphere is where pollutants come into contact with the plants or remediation agents (30). Plant roots play a crucial role in reducing pollutants in leachate (31). Rhizobacteria also support pollutant reduction in the rhizosphere. The interaction between plant roots and microbes contributes to

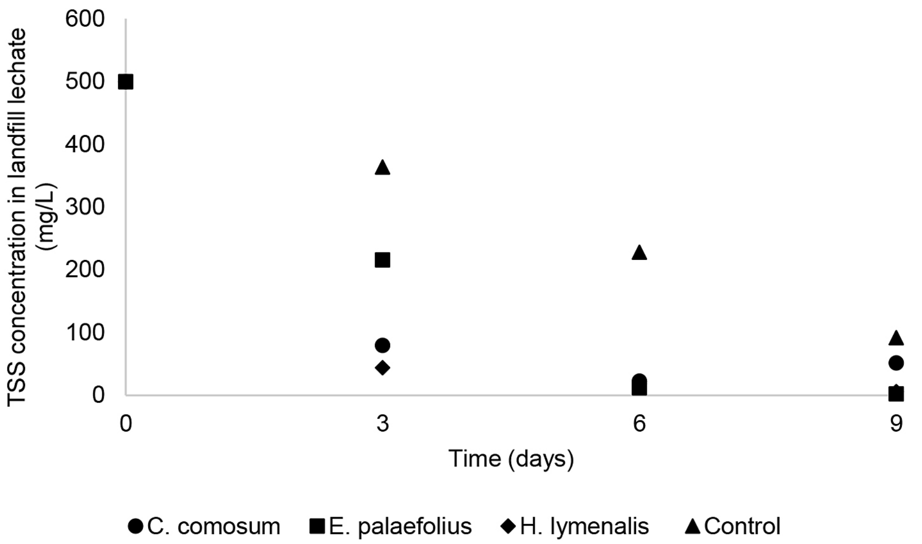


Figure 3. The decrease of the TSS concentration in landfill leachate

the removal of contaminants from the contaminated medium (32).

The efficiency of TSS reduction in the *C. comosum* reactor reached 99.68% by the end of the study. The TSS reduction efficiencies in the *E. palaefolius* and *H. lymenalis* reactors were 99.52% and 98.80%, respectively, on day 9 (Figure 4). The control reactor showed a TSS reduction efficiency of 81.60% on day 9. Compared to studies by (20, 21) *C. comosum, E. palaefolius*, and *H. lymenalis* were shown to reduce TSS concentrations in leachate range of 88.14–94.40%.

The decrease of TN concentration in landfill leachate

The initial TN concentration in all four reactors was 4,955.92 mg/L. A significant reduction in TN concentration was observed across all phytoremediation reactors (Figure 5). By day 3, TN levels had sharply decreased in all three reactors, with concentrations of 1,000.54 mg/L in the C. comosum reactor, 763.40 mg/L in the E. palaefolius reactor, and 682.19 mg/L in the H. lymenalis reactor. The final TN concentration in the leachate did not meet the quality standards set by (24), which requires a TN level of 60 mg/L.

The phytoremediation process, which utilizes the symbiotic relationship between plants and microorganisms in the reactors, contributed to the reduction of nitrogen in the leachate. Processes such as ammonification, nitrification, and denitrification also play a role in lowering TN levels. (33) explained that during phytoremediation, bacteria convert nitrogen through ammonification, nitrification, denitrification, and anaerobic ammonia oxidation, as well as nitrate and nitrogen fixation. TN levels decrease as plants absorb water, with microorganisms aiding in this process and transforming TN into energy for biomass production, while also releasing oxygen to reduce nitrogen levels. Nitrogen is a vital nutrient for plants, and in leachate, nitrogen generally exists in three forms: organic nitrogen compounds, ammonium ions (NH_4^+), and nitrate ions (NO_3^-). The nitrogen content in waste decreases because it serves as an essential nutrient for plants (10).

(34) stated that TN levels decrease in phytoremediation through the processes of phytostabilization, rhizodegradation, rhizofiltration, phytodegradation, and phytovolatilization. Several essential processes involved in phytoremediation technology to reduce TN levels are phytodegradation, rhizofiltration, and rhizodegradation. The phytodegradation process involves the decomposition of contaminants absorbed by plants through metabolic processes (14). The rhizofiltration and rhizodegradation processes remove pollutants using plant roots. This method is mostly effective for remediation of soil and water highly contaminated with nutrients like nitrogen and phosphorus (35). Rhizosphere nitrification by plant roots followed by denitrification can reduce ammonia levels in wastewater (36).

Plants will easily absorb nitrogen in the form of NO_3 through the processes of ammonification and nitrification (37). The ammonification process changes the levels of organic N which is

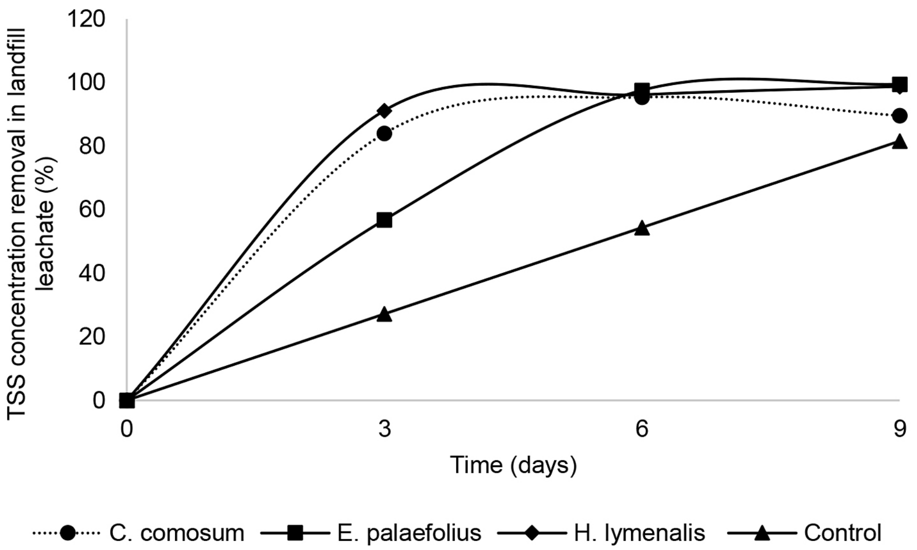


Figure 4. The TSS concentration removal efficiency in landfill leachate

converted into NH_3 or NH_4^+-N. The nitrification process which will convert NH_3 or NH_4^+-N levels into NO_3^--N involves the microorganisms *Nitrosomonas* and *Nitrobacter* (33). Nitrification has not yet removed the nitrogen levels in the leachate. To achieve the goal of removing nitrogen, the denitrification process is continued, where the NO_3^--N levels are reduced by heterotrophic bacteria to N_2, then the nitrogen is released in the form of N_2 gas. Plants can absorb dissolved N and provide a medium for microbial growth. Plant root exudates in the rhizodegradation process can further encourage the growth of microorganisms and increase the rate of nitrification and denitrification (37).

The efficiency of TN reduction in the phytoremediation process was observed in all reactors (Figure 6). The TN reduction efficiency for *C. comosum, E. palaefolius*, and *H. lymenalis* reached 94.75%, 89.19%, and 91.28%, respectively, by day 9. The control reactor also showed a decrease in TSS levels, with a lower efficiency of 83.71% at the end of the research. This TN reduction efficiency was higher compared to the research conducted by (38). (38) found that nitrogen reduction using *E. palaefolius* could reach 83.67% with a hydraulic retention time (HRT) of 3.1 days. An extended retention time can lead to a greater reduction in nitrogen levels. Nitrogen reduction in wastewater treatment occurs through two main mechanisms: nitrification and

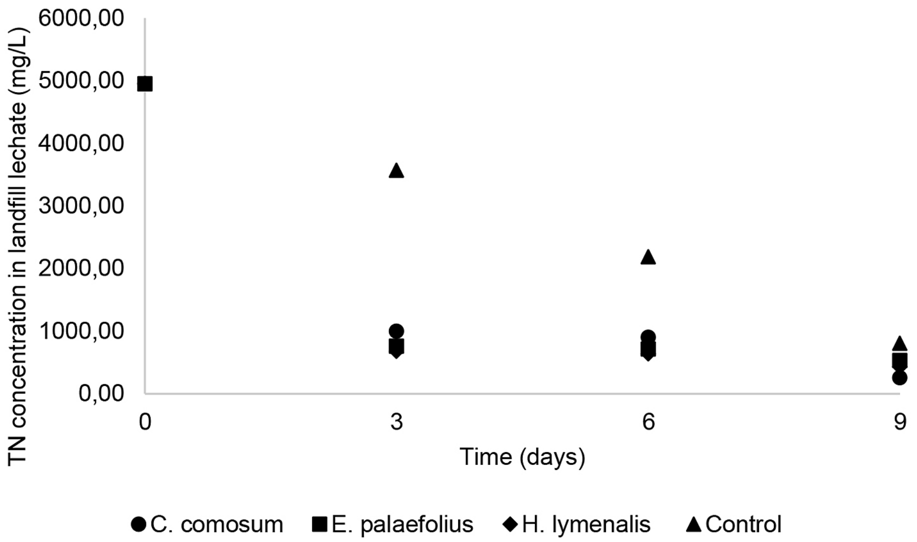


Figure 5. The decrease of the TN concentration in landfill leachate

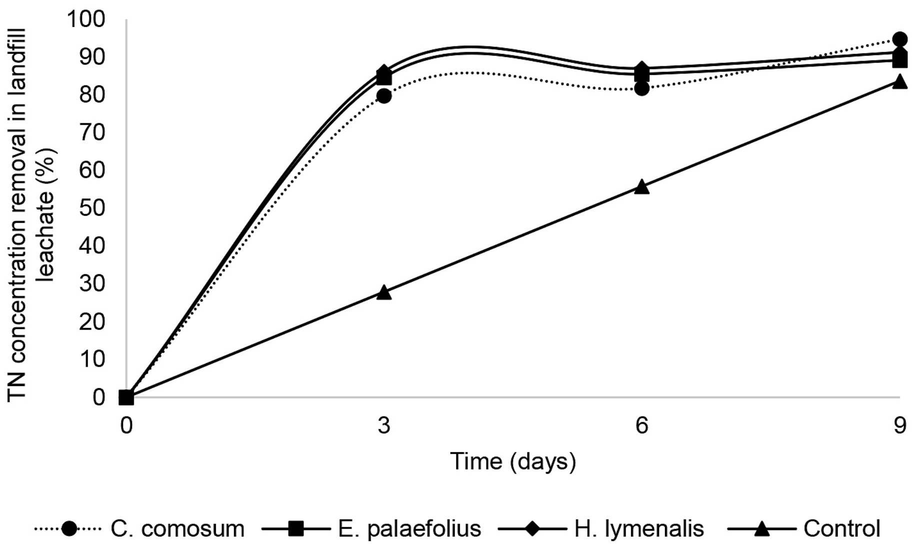


Figure 6. The TN concentration removal efficiency in landfill leachate

denitrification. In the nitrification process, which is aerobic, the plant's rhizome roots transfer oxygen to the wastewater at the reactor's base. Microorganisms also play a role in nitrogen reduction in wastewater.

The decrease of Cd concentration in landfill leachate

The initial concentration of Cd in the leachate across all reactors was 0.0150 mg/L. During the phytoremediation process, Cd levels gradually decreased from the start to the end of the experiment (Figure 7). The final Cd concentrations in reactors with *C. comosum*, *E. palaefolius*, and *H. lymenalis* were 0.0003 mg/L, 0.0003 mg/L, and 0.0010 mg/L, respectively, while the control reactor had a final concentration of 0.0030 mg/L. The reduction in cadmium levels is attributed to the phytoremediation process, which incorporates four plant-based technologies: phytoextraction, phytostabilization, rhizofiltration, and phytovolatilization (39). Among the four phytoremediation technologies, phytoextraction is the most commonly used method for extracting heavy metal contaminants (23). In the process of phytostabilization, plants immobilize heavy metals, thereby reducing their bioavailability in landfill leachate (17).

The mechanism of heavy metal absorption in the phytoextraction process involves the absorption of heavy metals by translocation of contaminants by plant roots into plant tissue (35). The hyperaccumulator plants accumulate higher concentrations of heavy metals in their root and shoot tissues. Remediation can be achieved through immobilization of pollutants in the roots or rhizosphere, which is the phytostabilization process (19). Plant exudates can allow contaminants to be immobilized in the rhizosphere. Heavy metals can be converted into non-toxic compounds through the formation of sugars, proteins, amino acids or making complexes in the rhizosphere (40). Rhizofiltration involves the removal of heavy metals using plant roots in leachate water through adsorption and precipitation into the roots. In this process, plant roots absorb contaminants and clean leachate. Rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn, and Cr, which are retained in the roots. Phytovolatilization is the process by which plants take contaminants from the medium and transform the less volatile chemicals into more volatile forms and remove the contaminants into the atmosphere through the process of volatilization (17). Phytovolatilization may also cause diffusion of contaminants from the stem or other plant parts through which the contaminants travel before reaching the leaves.

The efficiency of Cd reduction in all four reactors showed a sharp decline from day 6 to the end of the study (Figure 8). On day 6, the efficiency of Cd reduction in *C. comosum, E. palaefolius, H. lymenalis*, and the control reactors was 66.67%, 93.33%, 80.00%, and 62.67%, respectively. By the end of the research, the Cd reduction efficiency in the *C. comosum, E. palaefolius*, and *H. lymenalis* reactors was 97.99%, 97.87%,

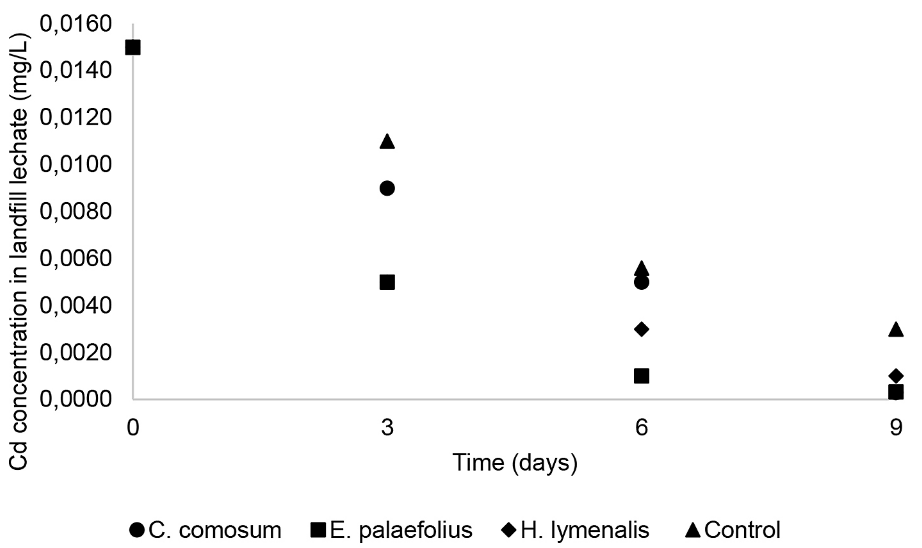


Figure 7. The decrease of the Cd concentration in landfill leachate

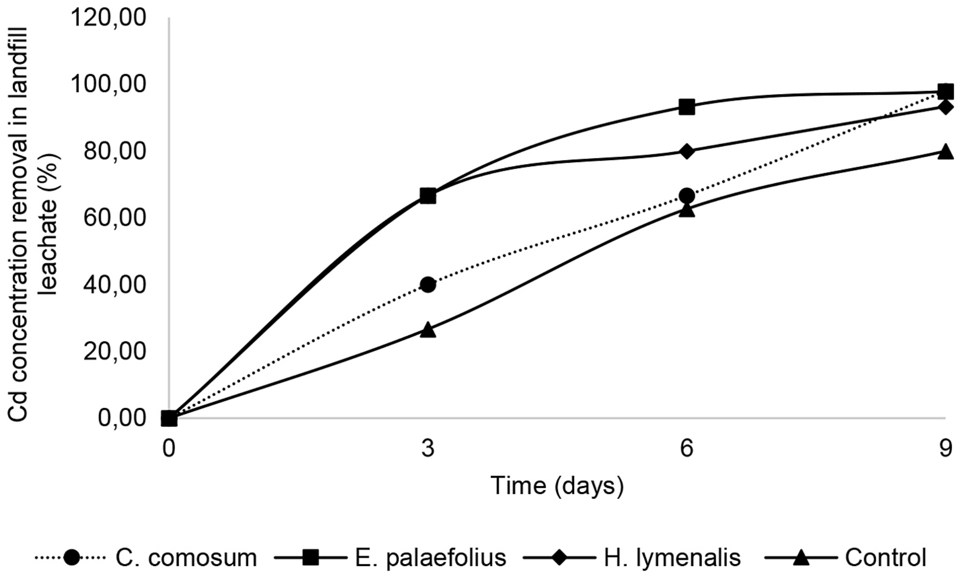


Figure 8. The Cd concentration removal efficiency in landfill leachate

and 93.33%, respectively. The control reactor achieved a Cd reduction efficiency of 80%.

pH value and temperature in landfill leachate

The pH values in the planting media with *C. comosum, E. palaefolius*, and *H. lymenalis* during the study ranged from 7.0 to 8.0. The increase in pH was due to the higher consumption of CO_2 during the photosynthesis process (9). The planting media had a neutral pH value of 6.0–7.0. This indicates that the pH levels in the planting media of all reactors were within the optimal range for plant growth and productivity, as well as for microorganisms in the soil.

The temperature values in the planting media containing *C. comosum, E. palaefolius*, and *H. lymenalis* showed changes from day 0 until the end of the study. The average temperature in the planting media ranged from 28 °C to 30 °C. This temperature range falls within the mesophilic range, which is between 25 °C and 40 °C, where biological water recovery processes occur (41). The temperature in the planting media was within the optimal range, allowing plants to grow and microorganisms in the media to thrive, contributing to soil fertility.

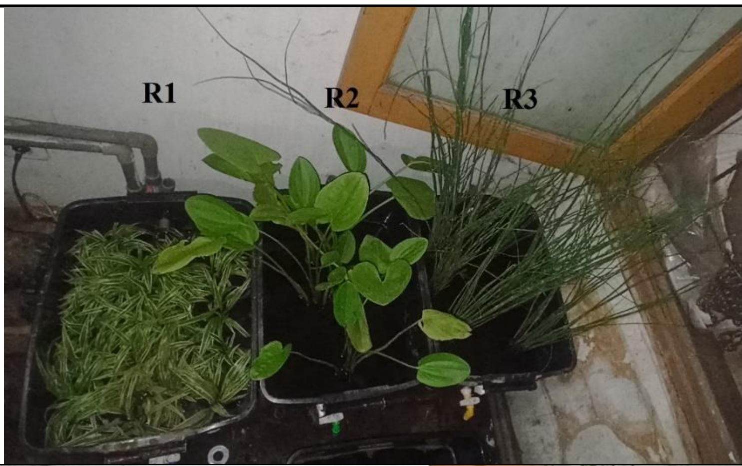
The pH and temperature values in the planting media during the phytoremediation research from the beginning to the end of the research were in the range of optimal conditions for plant growth and microbial activity in the phytoremediation process. The efficiency of reducing TN and Cd levels in leachate that occurs during the phytoremediation process is due to the existence of suitable conditions for the phytoremediation process.

Plants growth monitoring

Observational photos of *C. comosum, E. palaefolius*, and *H. lymenalis* from the beginning to the end of the research are presented in Table 2. On day 6 of the study, physical changes were observed in *E. palaefolius*, where several leaves appeared yellow. By the end of the study, the leaves of *C. comosum* and *H. lymenalis* had become wilted and yellow. According to (42) yellowing or chlorosis in plants is a primary symptom of contaminant toxicity, which leads to brown roots, a decrease in leaf count and root size, and damage to root caps.

The specific impact caused by contaminants in leachate is that changes in leaf color on *E. palaefolius* begin to appear on day 6 and day 9. *C. comosum* and *H. lymenalis* began to show physical changes on day 9. It can be said that *C. comosum* and *H. lymenalis* were able to survive compared to *E. palaefolius* plants. Yellowing or chlorotic leaves indicate that leachate is disrupting plant metabolism. Maximum concentration to be used on phytotreatment should not disturb the plants metabolism. Leachate contamination uptake studies conducted by (43) showed that roots have the ability to absorb significant quantity of leachate contamination and also have the ability to restrict its translocation to plant parts. When

Table 2. Physical observation of *C. comosum*, *E. palaefolius*, *and H. lymenalis* throughout 9 days exposure

Time	Reactor	
Day 0		
Day 3		
Day 6		
Day 9		
	R1: *C. comosum*, R2: *E. palaefolius*, R3: *H. lymenalis*, R4: control	

leachate contamination enters plant cells, even in small amounts, it can produce a wide range of effects in physiological processes such as inhibition of enzyme activity, disruption of nutritional minerals, water imbalance, changes in hormonal status and altered membrane permeability. At high concentrations of leachate contamination, it can ultimately cause death.

CONCLUSIONS

The final concentration of TSS in the landfill leachate for the reactors with *C. comosum, E. palaefolius*, and *H. lymenalis* was 1.6 mg/L, 2.4 mg/L, and 6 mg/L, respectively. The efficiency of TSS reduction in the leachate for *C. comosum, E. palaefolius*, and *H. lymenalis* reactors was 99.68%, 99.52%, and 98.80%, respectively. The final concentration of TN in the landfill leachate for *C. comosum, E. palaefolius*, and *H. lymenalis* reactors was 260.20 mg/L, 535.75 mg/L, and 432.30 mg/L, respectively, with the TN removal efficiency for *C. comosum* being 94.75%, *E. palaefolius* 89.19%, and *H. lymenalis* 91.28%. The final concentration of Cd in the landfill leachate for *C. comosum* was 0.0003 mg/L, for *E. palaefolius* 0.0003 mg/L, and for *H. lymenalis* 0.0010 mg/L. The Cd removal efficiency was 97.99% for *C. comosum*, 97.87% for *E. palaefolius*, and 93.33% for *H. lymenalis*. The final TSS and Cd concentrations in the landfill leachate met the regulatory quality standards of 100 mg/L for TSS and 0.1000 mg/L for Cd. However, the final TN concentration in the landfill leachate did not meet the quality standard of 60 mg/L.

Acknowledgements

This research was supported by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia under the Fundamental Research Grant 2024, Contract No. 109/E5/PG.02.00.PL/2024; 034/SP2H/PT/LL7/2024; 070.18 / Kontrak / LPPM / VI / 2024.

REFERENCES

1. Touzani A, El Hammoudani Y, Dimane F, Tahiri M, Haboubi K. 2024. Characterization of leachate and assessment of the leachate pollution index – a study of the controlled landfill in fez. Ecol Eng Environ Technol. 25(4), 57–69.
2. Abdel-Shafy HI, Ibrahim AM, Al-Sulaiman AM, Okasha RA. 2024. Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview. Ain Shams Eng J. 15(1), 102293. https://doi.org/10.1016/j.asej.2023.102293
3. Saeed T, Miah MJ, Majed N, Hasan M, Khan T. 2020 Aug 1. Pollutant removal from landfill leachate employing two-stage constructed wetland mesocosms: co-treatment with municipal sewage. Environ Sci Pollut Res. 27(22): 28316–32. https://link.springer.com/article/10.1007/s11356-020-09208-y
4. Bakhshoodeh R, Alavi N, Oldham C, Santos RM, Babaei AA, Vymazal J, Paydary P. 2020 Mar 1. Constructed wetlands for landfill leachate treatment: A review. Ecol Eng. 146, 105725.
5. Ratnawati R, Sugito, Khoiriyah SFU. 2024. Treatment for landfill leachate utilize coagulation-flocculation combined with biofilter. In: Jurnal Teknologi Lingkungan. 94–101.
6. Nurhayati I, Ratnawati R, Sutrisno J, Pramana YB, Oktavitri NI. 2021. microalgae scenedesmus sp potential in phytoremediation of kalidami retention pond with potassium and carbon addition. Pollut Res. 40(1), 194–8.
7. Aveiga A, Banchón C, Sabando R, Delgado M. 2023. Exploring the phytoremediation capability of Athyrium filix-femina, Ludwigia peruviana and Sphagneticola trilobata for heavy metal contamination. J Ecol Eng. 24(7), 165–74.
8. Ketaubon P, Ritthikasem N, Tanheng P, Prapagdee B. 2024. Enhancing heavy metal phytoremediation in landfill soil by *Chrysopogon zizanioides* (L.) roberty through the application of bacterial-biochar pellets. Environ Technol Innov. 35, 103738. https://doi.org/10.1016/j.eti.2024.103738
9. Ratnawati R, Faizah. 2020. Phytoremediation of mercury contaminated soil with the addition of compost. J Eng Technol Sci. 52(1), 66–80.
10. Sial TA, Teewno AM, Memon SA, Mahar RB, Korai MS. 2023. Municipal solid waste landfill leachate treatment by Phragmites australis, Typha latifolia and Scirpus validus through Constructed Wetlands. J Ecol Eng. 24(6), 303–14.
11. Ratnawati R, Sari DP, Mukhtarr NA. 2024. Leachate treatment using sub-surface flow constructed wetland by Hippochaetes lymenalis. J Nat Resour Environ Manag. 14(2), 298–305.
12. Mangkoedihardjo S, Arliyani I. 2023. Performance of selected plants based growth on landfill leachate treatment using wetland application. Israa Univ J Appl Sci. 6(2), 71–84.
13. Yuliasni R, Kurniawan SB, Marlena B, Hidayat MR, Kadier A, Ma PC. 2023. Recent progress of phytoremediation-based technologies for industrial wastewater treatment. Phycoremediation Process Ind

Wastewater Treat. 24(2), 21–42.

14. Bhat SA, Bashir O, Ul Haq SA, Amin T, Rafiq A, Ali M, Américo-Pinheiro JHP, Sher F. 2022. Phytoremediation of heavy metals in soil and water: An eco-friendly, sustainable and multidisciplinary approach. Chemosphere. 303(1), 134788. https://doi.org/10.1016/j.chemosphere.2022.134788
15. Makarova A, Nikulina E, Avdeenkova T, Pishaeva K. 2021. The improved phytoextraction of heavy metals and the growth of Trifolium repens L.: The role of K2HEDP and plant growth regulators alone and in combination. Sustain. 13(5), 1–18.
16. Medina-Díaz HL, López-Bellido FJ, Alonso-Azcárate J, Fernández-Morales FJ, Rodríguez L. 2024. A new hyperaccumulator plant (*Spergularia rubra*) for the decontamination of mine tailings through electrokinetic-assisted phytoextraction. Sci Total Environ. 912(December 2023).
17. Yan A, Wang Y, Tan SN, Mohd Yusof ML, Ghosh S, Chen Z. 2020. Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. Front Plant Sci. 11, 1–15.
18. Shahid MJ, AL-surhanee AA, Kouadri F, Ali S, Nawaz N, Afzal M, 2020. Role of microorganisms in the remediation of wastewater in floating treatment wetlands: A review. Sustain. 12(14), 1–29.
19. Saran A, Fernandez L, Cora F, Savio M, Thijs S, Vangronsveld J, Merini LJ. 2020. Phytostabilization of Pb and Cd polluted soils using Helianthus petiolaris as pioneer aromatic plant species. Int J Phytoremediation. 22(5), 459–67.
20. Mirwan M, Pramesti TA. 2023. Reducing TSS and COD of leachate with constructed wetland using water jasmine (Echinodorus palaefolious) and spider plant (*Chlorophytum comosum*). 239–44.
21. Ramadhani J, Asrifah RD, Wahyuning I. 2019. Leachate treatment using the constructed wetland method at the Tanjungrejo Waste Landfill, Tanjungrejo Village, Jekulo District, Kudus Regency. Geo-Environmental Sci J. 1(12), 1–8.
22. Tangahu BV, Ningsih DA, Kurniawan SB, Imron MF. 2019. Study of BOD and COD removal in batik wastewater using Scirpus grossus and Iris pseudacorus with intermittent exposure system. J Ecol Eng. 20(5), 130–4.
23. Ratnawati R, Fatmasari RD. 2018. Phytoremediation of lead (Pb) contaminated soil using Sansevieria trifasciata and Celosia plumosa. Al-Ard J Tek Lingkung. 3(2), 62–9.
24. Minister of Environment and Forestry of the Republic of Indonesia 2016. No. P.59. About Leachate Landfill Quality Standard and/or Activities of Landfill. 1–12.
25. Nurhayati I, Ratnawati R, Sugito. 2019. Effects of potassium and carbon addition on bacterial algae bioremediation of boezem water. Environ Eng Res. 24(3), 495–500.
26. Ratnawati R, Nurhayati I, Titis N, Oktavitri NI. 2020. Kalidami retention ponds phytoremediation with nutrient addition from *Scenedesmus* sp.: A microlagae. Pollut Res. 39(4), 1042–6.
27. American Public Health, American Water Works. 2023. A Waster Environment F. Standard Methods for the Examination of Water and Wastewater, 24th ed. In: Lipps WC, Bram-Howland EB, Baxter TE: Washington DC: APHA Press.
28. Ilmannafian AG, Kiptiah M, Darmawan MI. 2021. The effectiveness of filtration and phytoremediation with combination of aquatic plants in wastewater treatment of Sasirangan industry. IOP Conf Ser Earth Environ Sci. 926(1).
29. Purwanti IF, Obenu A, Tangahu BV, Kurniawan SB, Imron MF, Abdullah SRS. 2020. Bioaugmentation of Vibrio alginolyticus in phytoremediation of aluminium-contaminated soil using Scirpus grossus and Thypa angustifolia. Heliyon. 6(9), e05004. https://doi.org/10.1016/j.heliyon.2020.e05004
30. Ismail N 'Izzati, Abdullah SRS, Idris M, Kurniawan SB, Effendi Halmi MI, AL Sbani NH, Jehawi SH, Hasan HA. 2020. Applying rhizobacteria consortium for the enhancement of Scirpus grossus growth and phytoaccumulation of Fe and Al in pilot constructed wetlands. J Environ Manage. 267, 110643. https://doi.org/10.1016/j.jenvman.2020.110643
31. Al-Ajalin FAH, Idris M, Abdullah SRS, Kurniawan SB, Imron MF. 2020. Evaluation of short-term pilot reed bed performance for real domestic wastewater treatment. Environ Technol Innov. 20, 101110. https://doi.org/10.1016/j.eti.2020.101110
32. Jehawi OH, Abdullah SRS, Kurniawan SB, Ismail N 'Izzati, Idris M, Al Sbani NH, Muhamad MH, Hasan HA. 2020. Performance of pilot Hybrid Reed Bed constructed wetland with aeration system on nutrient removal for domestic wastewater treatment. Environ Technol Innov. 19, 100891. https://doi.org/10.1016/j.eti.2020.100891
33. Rahimi S, Modin O, Mijakovic I. 2020. Technologies for biological removal and recovery of nitrogen from wastewater. Biotechnol Adv. 43, 107570. https://doi.org/10.1016/j.biotechadv.2020.107570
34. Harne K, Joshi H, Wankhade R. 2022. Phytoremediation an effective technique for domestic wastewater treatment phytoremediation: An effective technique for domestic wastewater treatment. Res Sq. https://doi.org/10.21203/rs.3.rs-1955793/v1
35. Kafle A, Timilsina A, Gautam A, Adhikari K, Bhattarai A, Aryal N. 2022. Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. Environ Adv. 8, 100203. https://doi.org/10.1016/j.envadv.2022.100203

36. Sikhosana MLM, Botha A, Monyatsi LM, Coetzee MAA. 2020. Evaluating the effect of seasonal temperature changes on the efficiency of a rhizofiltration system in nitrogen removal from urban runoff. J Environ Manage. 274(111192).
37. Chamoli A, Bhambri A, Karn SK, Raj V. 2024. Ammonia, nitrite transformations and their fixation by different biological and chemical agents. Chem Ecol. 40(2), 166–99.
38. Pramesti TA, Mirwan M. 2023. Removal TSS, COD, and Total Nitrogen leachate with constructed wetland using water jasmine (*Echinodorus palaefolius*). J Pengendali Pencemaran Lingkung. 5(2), 189–95.
39. Ahmad I, Alserae H, Zhu B, Zahoor A, Farooqi ZUR, Mihoub A, Ain QU, Radicetti
40. E. 2024. Phytoremediation of Cadmium: A Review. Springer Water.; Part F 2532, 75–99.
41. Sophia S, Shetty Kodialbail V. 2020. Phytoremediation of soil for metal and organic pollutant removal. Vol. 104, Bioprocess Engineering for Bioremediation. 45–66.
42. Varma M, Gupta AK, Ghosal PS, Majumder A. 2021. A review on performance of constructed wetlands in tropical and cold climate: Insights of mechanism, role of influencing factors, and system modification in low temperature. Sci Total Environ. 755.
43. Nirwisaya PM, Titah HS. 2023. Phytotoxicity test of cadmium and lead on Sunflower (Helianthus annuus L.) as first step in phytoremediation. In: IOP Conference Series: Earth and Environmental Science.
44. Šourková M, Adamcová D, Zloch J, Skutnik Z, Vaverková MD. 2020. Evaluation of the phytotoxicity of leachate from a municipal solid waste landfill: The case study of bukov landfill. Environ. 7(12), 1–14.