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Phytoremediation of landfill leachate using *Ipomoea aquatica* and *Pistia stratiotes*

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Abstract

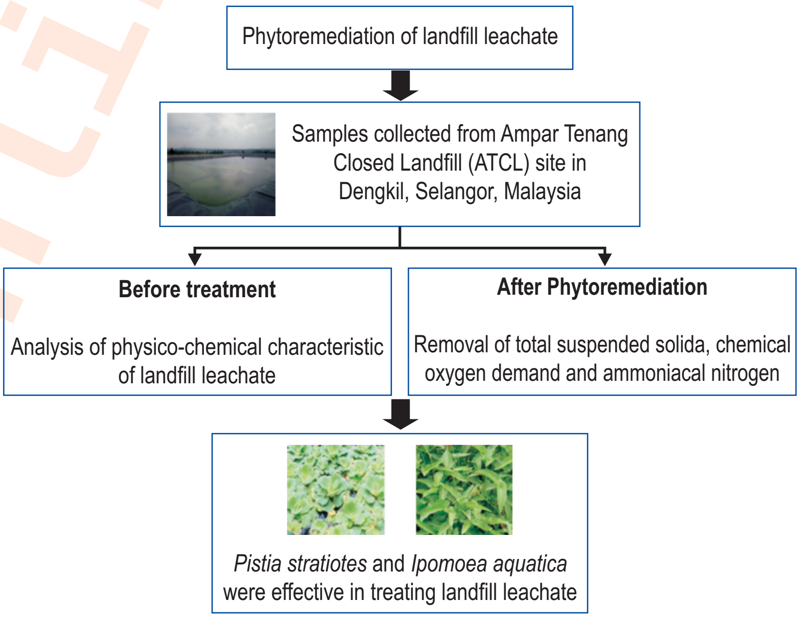
Aim: In this study, *Ipomoea aquatica* and *Pistia stratiotes* were used to remove total suspended solids, chemical oxygen demand and ammoniacal nitrogen (NH_3-N) from the landfill leachate collected at Ampar Tenang Closed Landfill (ATCL) site in Dengkil, Selangor, Malaysia.

Methodology: The physico-chemical characteristics of landfill leachate (pH, temperature, NH_3-N, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total dissolved solids, total suspended solids, salinity, electrical conductivity and nitrite as well as selected heavy metals were determined before phytoremediation treatment.

Results: The physico-chemical properties of leachate samples were found to be lower as compared to the standards set by the government, except for COD (>100 mg l^{-1}). Heavy metals content, Na, Mg and Fe was high in leachate. It was found that the concentrations of NH_3-N, COD and TSS in leachate decreased by 57.64%, 26.85% and 62.05% after treatment with *Ipomea aquatica*, respectively. Whereas, 61%, 32% and 74.7% removal rate was observed for NH_3-N, COD and TSS, post-treatment by *Pistia stratiotes.* One-way ANOVA analysis for *Ipomoea aquatica* revealed insignificant difference ($p>0.05$) but for *Pistia stratiotes* there was a significant difference ($p<0.05$) in the reduction of TSS, COD and NH_3-N concentrations.

Interpretation: Based on the findings, *Pistia stratiotes* was found more effective than *Ipomea aquatica* for reducing TSS, COD and NH_3-N concentrations from landfill leachate.

Key words: *Ipomoea aquatica,* Landfill waste, Leachate treatment, Phytoremediation, *Pistia stratiotes*



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Introduction

The rapid growth of population and economic development has resulted in increased water supply and demand for living, industrial as well as agricultural needs (Hanafiah *et al*., 2018a; Harun and Hanafiah, 2018). Water resource is important because it is limited and needs to be managed carefully. Nonetheless, clean water supply is becoming scarce and further deterioration of water due to pollution is affecting the quality of water (Hanafiah *et al*., 2018b; 2018c). Contaminants present in water body can adversely affect the environment and human health (Al-Raad *et al*., 2020). Therefore, contaminated water resource should be treated before being released into the environment.

Among various water pollution, discharge of leachate is one of the crucial issues for municipal solid waste landfill (Banch *et al*., 2019a; Banch *et al*., 2020a). In the case of municipal solid waste disposal sites, leachate is generated during the process of decomposition of solid waste (Halim *et al*., 2017). The main problems associated with waste disposal sites are the production of leachate and release of harmful CH_4 gas (Banch *et al*., 2020b). The release of leachate from landfill in the environment is a concern due to toxic nature of leachate that can have deterioration effects on human health (Banch *et al*., 2019b). In addition, heavy metals present in leachate are highly toxic when their concentration exceeds the permissible limit set by the regulatory bodies limit (Shaikh *et al*., 2019).

Landfill leachate usually contain large amount of dissolved organic matter, biochemical oxygen demand, chemical oxygen demand, xenobiotic organic compounds, inorganic salts, ammonia, heavy metals and other toxic substances (Halim *et al*., 2015). More than 200 organic compounds have been identified in leachate of municipal landfills, of which more than 35 compounds have the potential to pose negative impacts on the environment and human health (Brennan *et al*., 2016). High level of ammonia in water may lead to eutrophication and depletion of dissolved oxygen in water (Ghosh *et al*., 2017). Organic pollutants present in the environment are mainly derived from human and xenobiotic to organisms, with most pollutants being toxic and carcinogenic in nature (Hanafiah *et al*., 2011). Organic pollutants are released into the environment through oil spills, explosive materials and chemical weapons, fertilizers and pesticides used in agriculture, chemicals and petrochemicals industries, timber treatment, etc. (Ashraf and Hanafiah, 2019; Aziz *et al*., 2019).

Phytoremediation is an environmentally friendly technique for treating contaminated soil, groundwater and sewage (Mahar *et al*., 2016). This technique is preferred for treating wastewater due to its low maintenance cost and is defined as green plant engineering (such as grass, rattan and woody species) for the removal of pollutants such as heavy metals, trace elements, organic compounds and radioactive compounds in soil and water (Sarwar *et al*., 2017). Phytoremediation is associated with the use of plants and microbes related to pollutants removal (Hanafiah *et al*., 2020). Phytoremediation utilizes natural processes by which plants and microbial rhizosphere remove organic and non-organic pollutants (Hanafiah *et al*., 2018b). Phytoremediation is also an effective cleaning method for eliminating various organic and inorganic contaminants. Several studies have been conducted to evaluate the potential of phytoremediation for treating leachate using various types of plants like *Typha latifolia*, *Eichhornia crassipes*, *Pistia stratiotes*, *Lemna minor, Egeria densa*, *Colocasia esculenta*, *Gynerum sagittatum* and *Heliconia psittacorum* (Abbas *et al*., 2019; Madera-Parra *et al*., 2015; Ohlbaum *et al*., 2018; Xu *et al*., 2020).

In view of the above, this study aimed to determine the quality of leachate before treatment at five different sampling points; stabilization pond, river, leachate inlet, leachate accumulation pond and leachate outlet and to determine the reduction rate of total suspended solids, chemical oxygen demand and ammoniacal nitrogen (NH_3-N) in leachate through phytoremediation by *Pistia stratiotes* (water lettuce) and *Ipomoea aquatica* (water spinach). *Pistia stratiotes* and *Ipomoea aquatica* were selecetd in this study because they are among the most suitable plants used in phytoremediation process. *Pistia stratiotes* and *Ipomoea aquatica* have the ability to absorb high nutrients, have faster growth rate and produce high biomass (Akinbile and Yusoff, 2012). These plants have been found to effectively reduce the TSS, COD and NH_3-N levels in contaminated water (Akinbile and Yusoff, 2012; Hanafiah *et al*., 2018b; Nizam *et al*., 2020). Therefore, this study was carried out to evaluate the reduction rate of contaminants in landfill leachate using *Pistia stratiotes* and *Ipomoea aquatica.*

Materials and Methods

Leachate sampling was carried out at Ampar Tenang Closed Landfill (ATCL) site in Dengkil, Selangor, Malaysia and was collected from five sampling points; stabilization pond, river, leachate inlet, leachate accumulation pond and leachate outlet. At each station, three replications of leachate samples were obtained. The test plants used in this study for treating leachate samples were *Pistia stratiotes* and *Ipomoea aquatica*. The physico-chemical properties of leachate were estimated before treatment and after 10 days of plant treatment.

Physico-chemical parameters of leachate was analyzed. Parameters like pH, temperature, NH_3-N, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total dissolved solids, total suspended solids, salinity, electrical conductivity and nitrate were estimated. The pH, temperature, DO, TDS, salinity, conductivity and nitrate content in leachate samples were recorded with YSI 5000 multiparameter instrument (YSI Inc., Yellow Springs, USA). NH_3-N analysis was conducted by Nessler method using Hach DR6000 spectrophotometer (HACH, Loveland, USA). Atomic absorption spectroscopy (Unicam 929 AA Spectrophotometer, UNICO, Franksville, WI, USA) was used to measure heavy metals. Chemcial oxygen demand was determined using HACH DR2500 (HACH, Loveland, USA). For the analysis of biochemical oxygen demand (BOD), the leachate samples were kept in an incubator for five days at 20°C and the value was determined by the following formula:

$$BOD_5 = DO_1 - DO_5$$

Where DO_1 is the initial reading of DO and DO_5 is the reading of DO at day 5

Total suspended solids in leachate samples was estimated by gravimetric method and calculated as follows:

$$TSS = (A - B) \div V \times 1000 \text{ ml}$$

Where, A is the weight of filter paper after filtration; B is the weight of filter paper before filtration and V is the volume of filtered water sample

Phytoremediation of leachate samples was conducted for three parameters; TSS, COD and NH_3-N. Fig. 1 shows the phytoremediation of landfill leachate by *Pistia stratiotes* and *Ipomoea aquatica*. Each container contained 6 l of water and 30 g of plant. The treatment was run for 10 days and the data were taken on days 0, 2, 4, 6, 8 and 10 to determine the the changes in reduction rate during the treatment.

Statistical analysis: Statistical analysis was carried out using IBM SPSS statistics software version 23. The comparisons of the means for each parameter after the phytoremediation treatment were measured for p-values, and the significant level was determined at $p<0.05$.

Results and Discussion

Table 1 shows the physico-chemical parameters of landfill leachate samples and the parameters were compared with Malaysian standards from the Ministry of Health (MOH) and the Department of Environment (DOE).

The DO content in the landfill leachate recorded a total of 3.62 mg l^{-1}. Standard issued by the Malaysian MOH is 8.0 mg l^{-1}. For pH parameter, the value was 7.14. According to the Malaysian MOH, the respective pH level was safe to be released into the river. The EC value 507.67 µS cm^{-1}. According to the National Water Quality Standards (NWQS), the standard value for EC is 1,000 µS cm^{-1}. The value for salinity parameter found in the leachate was 0.2 g kg^{-1}. The NWQS standard is 0.5%.

The TDS content in landfill leachate was 331.9 mg l^{-1} whereas the standard set by the MOH is approximately 1,000 mg l^{-1}. Accordingly, it was indicated that the leachate which has been treated using rock infiltration method can be released into the river. The temperature at the landfill site was 25.75°C. The COD content was 185 mg l^{-1}. While the value set by the MOH Malaysia is 50 mg l^{-1}. The COD level in the leachate was very high. In addition, referring to the DOE standard, the permissible range for COD is 100 mg l^{-1}. Further treatment should be performed to reduce the value of COD content.

The NH_3-N content in leachate sample was 0.89 mg l^{-1}, which was much lower than the permissible limit set by the Malaysian MOH (10 mg l^{-1}). The suspended solids was 0.0003 mg l^{-1}, which was also much lower than the standard value set by the DOE (50 mg l^{-1}). The nitrate content in leachate sample was 7.83 mg l^{-1} against the standard value of Malaysian MOH (10 mg l^{-1}) indicating that the landfill leachate had low nitrate content.

Heavy metals like zinc, aluminum, cadmium, copper, iron, magnesium, lead, nickel, lithium, sodium, chromium, arsenic and

Table 1 : Physico-chemical parameters of landfill

Parameter	Inlet	Stabilized	Outlet	River	MOH	DOE
DO	2.21	5.17	3.62	6.44	8.0	NA
pH	8.18	9.29	7.14	7.07	5.5-9.0	6.00-9.00
Conductivity (µS m^{-1})	3458.00	727.33	507.67	435.80	NA	NA
Salinity (g kg^{-1})	1.80	0.40	0.20	0.17	NA	NA
TDS	2276.33	473.67	331.90	241.73	1000	NA
Temperature (°C)	22.00	24.30	25.75	22.43	40	40
COD	910.00	353.33	185.00	28.67	50	100
NH_3-N	2.49	0.88	0.89	0.19	10	NA
TSS	46.00	54.33	27.67	17.67	NA	NA
BOD_5	2.09	3.09	3.45	3.81	20	50
Nitrate	1.77	10.63	7.83	7.07	10	NA

All units in mg l^{-1} except stated; NA = not available; Nitrate for aeration and inlet accumulation has been diluted x10; MOH = Ministry of Health; DOE = Department of Environment

Table 2 : Heavy metals content in landfill leachate

Heavy metals (mg l^{-1})	Inlet	Stabilized	Outlet	River	MOH	DOE
Zn	0.087	0.102	0.207	0.077	1.00	0.80
Al	0.272	0.106	0.118	0.120	NA	NA
Cd	0.001	0.000	0.000	0.000	0.01	0.01
Cu	0.032	0.004	0.008	0.002	0.20	0.08
Fe	4.885	1.067	0.614	0.478	0.30	1.00
Mg	31.332	4.497	5.080	1.894	NA	NA
Pb	0.005	0.012	0.004	0.000	0.01	0.08
Ni	0.067	0.010	0.009	0.003	NA	0.08
Li	0.008	0.003	0.005	0.002	NA	NA
Na	1490.187	176.179	105.320	74.689	NA	NA
Cr	0.107	0.008	0.008	0.002	NA	0.03
As	0.030	0.004	0.012	0.002	0.05	0.06
Mn	0.184	0.012	0.005	0.001	0.10	0.20

NA = Not available

manganese were detected in the landfill leachate (Table 2). The data showed the concentration of heavy metals were within the permissible limit for waste disposal sites (Yusoff *et al*., 2013). In this study, the concentration of Na, Mg, Al and Li in leachate was 105.32 mg l^{-1}, 5.080 mg l^{-1}, 0.118 mg l^{-1}, and 0.005 mg l^{-1}, respectively.

In addition, the Cd and Cu values were 0.0004 mg l^{-1} and 0.008 mg l^{-1}, against the permissible limit of DOE for Cd (0.006 mg l^{-1}) and Cu (0.075 mg l^{-1}). Fe and Pb content in leachate 0.614 mg l^{-1} and 0.00414 mg l^{-1}. These values were in fact lower than the standard values of DOE, *i.e.*, 1.0 mg l^{-1} for Fe and 0.075 mg l^{-1} for Pb. Cr and Ni content in leachate was 0.008 mg l^{-1} and 0.009 mg l^{-1}. The standard values set by DOE for these heavy metals were 0.03 mg l^{-1} and 0.075 mg l^{-1}, respectively. Finally, As and Mn showed the values of 0.012 mg l^{-1} and 0.005 mg l^{-1}, respectively. The standard values issued by the DOE for As is 0.06 mg l^{-1} and for Mn was 0.2 mg l^{-1}.

In this study, Na, Mg and Fe were present in high concentration at all sampling points. According to the previous study conducted in Ampar Tenang Landfill site, high concentrations of heavy metals are hazardous for human health and the landfill site can cause a serious groundwater pollution within its proximity (Yusoff *et al*., 2013). Based on the previous study of Banch *et al*., (2019b), natural coagulant from palm oil mill effluent are able to reduce heavy metals in the leachate samples.

Fig. 2 shows COD content in landfill leachate post-treatment with *Pistia stratiotes* and *Ipomoea aquatica* plants. COD content in leachate reduced by 32% post 10-day treatment with *Pistia stratiotes*. *Pistia stratiotes* was able to reduce the concentration of COD from 50 mg l^{-1} to 40 mg l^{-1} over a period of 14 days (Zimmels *et al*., 2006). The reduction rate of COD at day 2, 4, 6 and 8 of treatment was approximately 20%, 24%, 26% and 29%. According to Lu *et al*. (2011), *Pistia stratiotes*'s root have high ability and capacity to absorb nutrients. One-way ANOVA showed significant differences ($p<0.05$) in COD reduction in the leachate treatment from day 0 to day 10.

COD value of leachate treated with *Ipomoea aquatica* showed a decreasing trend from day 2 to day 4 where the COD content reduced to 148.33 mg l^{-1}. On day 10, the reading value was equivalent to 135.33 mg l^{-1}. One-way ANOVA showed that leachate treatment with *Ipomoea aquatica* showed insignificant difference ($p>0.05$). However, landfill leachate treated with *Ipomoea aquatica* reduced COD by 5%, 20%, 21.62%, 22.7% and 26.85% on day 2, 4, 6, 8 and 10, respectively. The result indicated that the use of *Ipomoea aquatica* was suitable for treating leachate to reduce COD content.

NH_3-N content in landfill leachate post-treatment with *Pistia stratiotes* and *Ipomoea aquatica* are shown in Fig. 3. Zimmels *et al*. (2006), reported that *Pistia stratiotes* was able to reduce NH_3-N level by 89%. In this study, the concentration of NH_3-N reduced by 61% with *Pistia stratiotes*. NH_3-N level was reduced approximately by 37%, 45%, 50% and 56% at day 2, 4, 6 and 8, respectively. One-way ANOVA showed significant difference ($p<0.05$) for NH_3-N reduction rate in the phytoremediation treatment from day 0 to day 10.

One-way ANOVA showed insignificant difference ($p>0.05$) in leachate treated with *Ipomoea aquatica*. However, the phytoremediation treatment using *Ipomoea aquatica* plants showed 57.64% reduction in NH_3-N level from day 0 to day 10. From day 0 to day 2, 4, 6 and 8, the reduction rate was about 15.4%, 46%, 41.2% and 54%, respectively.

Total suspended solids content in landfill leachate after 10-day treatment with *Pistia stratiotes* and *Ipomoea aquatica* are

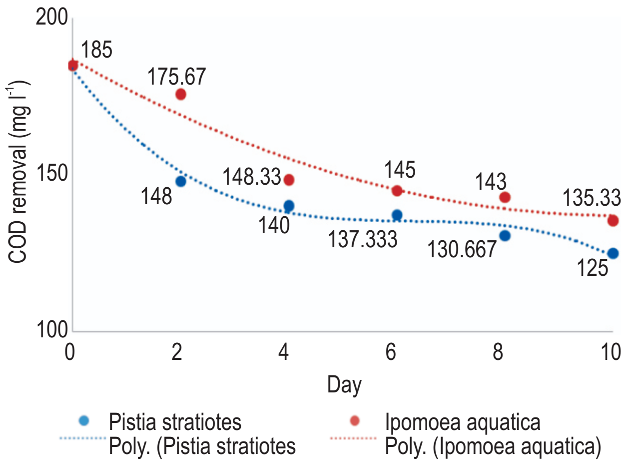

Fig. 2 : COD content in leachate treatment using *Pistia stratiotes* and *Ipomoea aquatica.*

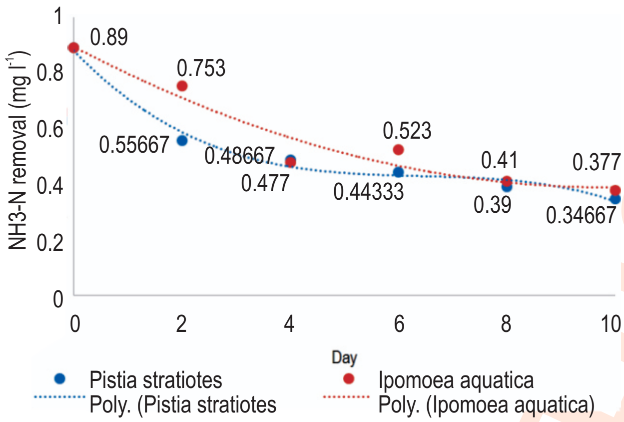

Fig. 3 : NH_3-N content in leachate treatment using *Pistia stratiotes* and *Ipomoea aquatica*.

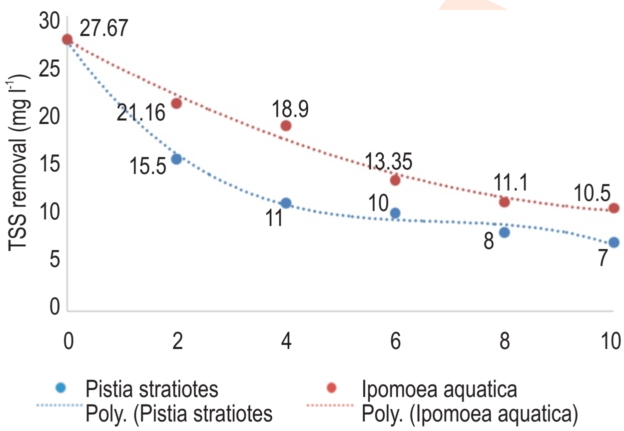

Fig. 4 : TSS content in leachate treatment using *Pistia stratiotes* and *Ipomoea aquatica.*

shown in Fig. 4. Lu *et al*. (2010) reported that *Pistia stratiotes* was able to reduce TSS content by approximately 10% in the treatment container compared to the control container. In this study, the phytoremediation treatment of leachate using *Pistia stratiotes* was capable of eliminating approximately 44%, 60.3%. 63.9%, 71% and 74.7% of TSS in the leachate on days 2, 4, 6, 8 and 10, respectively. One-way ANOVA showed a significant difference ($p<0.05$) in suspended solids in landfill leachate from day 2 to day 10. *Pistia stratiotes* was effective in absorbing suspended solids because of their root structure and hair (Lu *et al*., 2011). *Pistia stratiotes* has a well developed root system and stolons that act as filters, adsorb suspended matter and provide adhesive surfaces (Nizam *et al*., 2020).

Phytoremediation with *Ipomoea aquatica* reduced TSS content by 23.5%, 31.7%, 51.8%, 59.9% and 62.05% from day 0 to day 10. According to Malar *et al*. (2015), floating aquatic plants are easy to reproduce with high nutrients and produce high biomass in the aquatic environment without showing any toxic symptoms. Nizam *et al*. (2020) also found that *Pistia stratiotes* can absorb pollutants, especially at optimum conditions and produce high biomass. Therefore, phytoremediation plants in leachate sample have higher biomass than control plants. *Pistia stratiotes* is an invasive species, which can grow well in nutrient-rich waters, but was less effective in less nutrient-rich waters (Olguin *et al*., 2017).

Leachate at landfill site is a problematic issue, as it infiltrates into the ground and flows into nearby groundwater and rivers. The quality of leachate at Ampar Tenang landfill site was found to be detrimental and contained high organic and inorganic materials although it was treated before being released into the surrounding area. Therefore, phytoremediation is a good solution for leachate treatment as it is an environmentally friendly, low cost and does not require high technology. The selection of plants for this treatment is also important as weather and environmental factors of Malaysia needs to be taken into account in an effort to remove pollutants from water bodies.

Overall, the results of this study showed that *Pistia stratiotes* and *Ipomoea aquatica* were effective in treating landfill leachate and can act as a phytoremediations due to their ability to reduce the amount of TSS, NH_3-N and COD. These plants are suitable to be applied for phytoremediation process in Malaysia as they are distributed abundantly.

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Add-on Information

Authors' contribution: M.M. Hanafiah: Methodology, Supervision, Funding acquisition, Writing-original draft, Writing-review and editing; **N.I.H.A. Aziz:** Writing-original draft; **A.A. Halim:** Writing-review and editing; **L.S. Shamdin:** Formal analysis; **L.A.A. Razzak:** Formal Analysis.

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