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Original article

An efficacy investigation of combining Water Hyacinth (*Eichhornia crassipes*) with Filters as a Bioremediation for Leachate Contaminated Water

Agung Sih Kurnianto*, Shella Amalia Karisma Putri, Suci Ristiyana, Nanang Tri Haryadi, and Nilasari Dewi

Agrotechnology Study Program, Faculty of Agriculture, University of Jember

Abstract

Pollution occurs everywhere and threatens rice field that require good quality water. Leachate is a pollutant from the Final Disposal Site (TPA) and flows into irrigation in the surrounding area. This study aims to experimentally analyse using a combination of Water Hyacinth *Eichhornia crassipes* and filter media (zeolite, charcoal, and gravel) to improve irrigation water quality and performance in a limited time. Samples were obtained from TPA Pakusari, Jember, East Java, Indonesia (-8,16956, 113.76129). There were three treatments: control, Water Hyacinth (WH), and Water Hyacinth + Filter (WHF). Multiparameter Aquacombo HM 3070 was used to test the parameters of Total Dissolved Solid (TDS), Conductivity, and pH. Determination of DO levels was done by the Winkler Method. Sample tests were performed every day (0-14 days). TDS and pH measurements showed that WH was a treatment that significantly reduced the effect. OD measurements showed significant increases in WH and WHF on the 7th day but not significant again on the 14th day. BOD measurements showed that control and WH decreased significantly starting the seventh day. Only the control treatment differed significantly on day 14 for conductivity measurements. Principle Component Analysis (PCA) showed that the WH and WHF treatments differed significantly, as a set of measured parameters between treatments formed different clusters on days 7 and 14. The significance of this study lies in its potential contribution to developing effective and sustainable methods to mitigate water pollution in agricultural settings, particularly in regions affected by leachate from disposal sites. The findings could be pivotal in improving irrigation water quality, thereby supporting healthier crop growth and sustainable agricultural practices.

Keywords: Bioremediation, Filters, Leachate, and Water Hyacinth

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Introduction

Rice is a crop with high global consumption levels. High productivity demands necessitate substantial water usage during the vegetative growth phase (Muthayya et al., 2014; Afifah et al., 2015). However, this water requirement also dissolves various pollutants outside the agroecosystem area, including agrochemical inputs from fertilisers, pesticides, and other contaminants (Aulakh et al., 2010; Haseena et al., 2015). Contaminants, even in limited quantities, can accumulate in plants and adversely impact consumer health, as noted by Haseena et al., 2015. This phenomenon occurs globally and poses a significant threat to agroecosystems, compromising food security and drastically reducing food quality, as highlighted in studies by Vörösmarty et al., 2010 and Lu et al., 2015.

Pakusari TPA (The Central Landfill of Pakusari), with a land area of 6.8 Ha, is the most prominent waste collection location in Jember Regency (East Java Province, Indonesia), and it was located adjacent to the agroecosystem area. The Pakusari landfill can accommodate 4.024.429 tons of waste every month from all parts of Jember City (Isni et al., 2019). However, leachate from this landfill does not go through remediation treatment, thus threatening irrigation canals and the management of the surrounding rice agroecosystem. Leachate contains a lot of heavy metals and other organic pollutants, which is easily to seep and enter irrigation canals and agroecosystems (Abrauw, 2019). The influx of organic contaminants into the irrigation systems of rice farming can lead to nutrient enrichment, subsequently causing an increase in the population of aquatic weeds. This escalation in weed growth can negatively impact productivity (Li et al., 2018). Additionally, heavy metal content within these contaminants is prone to accumulate in the vacuoles of plant cells and may be released when the plants are consumed by animals and humans (Sharma et al., 2016).

Water Hyacinth (*Eichhornia crassipes*) has been reported to be a bioremediation agent, that can absorb heavy metal contamination and organic pollutants using various bioaccumulation ingredients (Saleh, 2016). Robust research related to the bioremediation progress and irrigation water monitoring quality has been carried out but rarely focuses on the threat of landfill leachate to rice crops which are very susceptible to contamination. Therefore, finding suitable remediation and management processes is necessary to reduce pollution's impact on food crops, especially rice management (Haseena et al., 2015). This study aims to experimentally analyse the use of a combination of Water Hyacinth and filter media to improve irrigation water quality and its performance in a limited time.

* Corresponding Author:
Agung Sih Kurnianto
Agrotechnology Study Program, Faculty of Agriculture, University of Jember, Indonesia
Phone: +62-81232767729 Fax: -
E-mail: agung.sih.kurnianto@unej.ac.id

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Methods

Leachate samples were taken from the irrigation stream with the point closest to the waste disposal in Pakusari, Jember Regency, East Java, Indonesia (-8.16956, 113.76129). A total of 18 reactors will be used to collect irrigation water samples, each containing 18 litres (L) of water. The reactor was made of a plastic bucket (20 L), and holes were made at the bottom for sampling. The Water Hyacinth (WH) treatment utilized water samples and five individual plants of the same size, aged 1-2 weeks. The combination treatment of Water Hyacinth and Filter (WHF) used filter media arranged from top to bottom with zeolite sand (10 cm), activated charcoal (15 cm), and gravel (20 cm), respectively (Figure 1). Activated charcoal, zeolite, and gravel are theoretically recognized as standard filters for water purification and reducing contamination levels, demonstrating their effectiveness against various organic pollutants and heavy metals. This arrangement has been effectively demonstrated to be capable of filtering various levels of contaminants (Audiyanti et al., 2019; Apriyani and Novrianti, 2020). Before treatments, all plants were acclimatised with tap water for three days (Hartanti et al., 2014).

Laboratory tests were conducted to observe the parameters of Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solute (TDS), Conductivity, and pH. Multiparameter Aquacombo HM 3070 (available for pH (2-12), DO (0-30 ppm), Conductivity (~2000 mS), Salinity (0-42 ppt), and temperature (0-60^{o}C) meter, made by Trans Instruments, Singapore) were used to test the parameters of Total Dissolved Solute (TDS), Conductivity, and pH. Determination of DO levels was done by the Winkler Method (Balderas, 2016). Sample testing was performed every day (0-14 days). The BOD value was obtained from the difference between the initial DO of the sample and the DO after the 15th (DO_0-DO_5), calculated for days 0, 7, and 14. Data were analysed by SPSS 16.0 using a variance at a 5% level and continued by the Duncan Multiple Range Test (DMRT) with a level of 5%. To illustrate fluctuations and interactions between the treatments, a scatter plot and Principal Component Analysis (PCA)-biplot graph were created using PAST 03 (Elshobary et al., 2020). As a limitation, this research focuses solely on the effectiveness of using Water Hyacinth and water filter media such as zeolite, charcoal, and gravel, as well as their combination in addressing the leachate waste from the Pakusari landfill in Jember.

Results

The results in several parameters show various descriptions of pollution reduction. The TDS parameter was significantly different on Day 7 (D7) and Day 14 (D14). In contrast, the OD parameter showed no significantly different (see Table 1.) The pH parameter showed significantly different results on D0 and very significant differences on D7 and D14. The DO measurement showed that the results were not significantly different on D0 and D14 and very significant differences on D7. BOD measurement results are very significantly different on D7 and significantly different on D14. Conductivity measurements showed that the results were not significantly different on D0 and D7 and significantly different on D14.

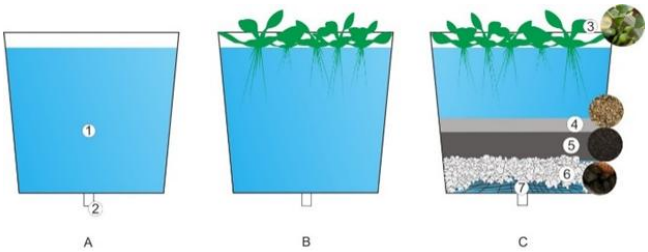

Figure 1. Reactor schematic. Keys = A: Control; B: WH; C: WHF; 1: Water Sample, 2: Sample collection site; 3: WH, 4: Zeolite Sand; 5: Activated Charcoal; 6: Gravel; 7: Plastic Mesh

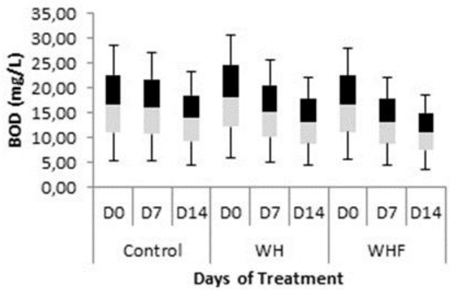

Figure 2. Boxplot of BOD measurement on Day 0 (D0), Day 7 (D7), and Day 14 (D14)

BOD values for all treatments decreased until D14. However, the control did not give a significant decrease (Figure 2). This evidence follows the hypothesis that leachate contamination in water will not be degraded naturally without treatment. The BOD value on D0 showed a value of 5.81 mg/L, and the combination treatment (WHF) gave the best results with a decrease of 3.75 mg/L. There was a significant reduction difference between the control, WH, and WHF (Figure 3). WH initiated a significant decrease in the TDS value reaching 712.48 mg/L (Table 1). The combination (WHF) treatment also effectively lowered TDS (Figure 3).

The pH value for the WH and WHF treatment decreased every day of observation, while the control treatment did not change and tended to increase. This can be seen from the results obtained that the pH in the irrigation water sample is alkaline, and during the observation, the pH changes to neutral. The pH of irrigation water on D0 was on the alkaline scale (8.30), which was caused by contamination of irrigation water by leachate. The decomposition process influences this evidence in organic waste piles. The increased control results were suspected to be undergoing a decomposition process which increased pH. Successful decomposition will release most of the carbon into the water, one of which is CO_2. An alkaline pH is produced due to the anaerobic decomposition process producing CO_2 gas and heavy metals such as iron and manganese, causing the pH to rise. The highest pH decrease occurred on the 14th day and was shown in WH (7.42), followed by WHF (7.5).

The DO value of WH and WHF increased until D7, while in the control treatment, it decreased throughout the observation. In the control treatment, the decrease in DO on D14 was the lowest (6.68 mg/L), and the WHF treatment showed the most compelling difference (6.88 mg/L). However, our study showed that the DO value on the 14th day decreased. We assume microalgae blooming occurred inside the reactor. This evidence is one of the experimental limitations, where the factor of using oxygen together in a limited living space is unavoidable. Temporarily, sufficient dissolved oxygen will be used by many organisms in a narrow space. This resulted in a significant decrease in the second week of observations.

The Conductivity decreased slowly in both treatments, and no significant difference was observed (see Figure 3). However, both are considered capable of reducing the conductivity of polluted water. PCA analysis showed that the WH and WHF treatments differed significantly, as a set of measured parameters between treatments formed different clusters on days 7 and 14 (Figure 4). However, there were no significant differences between WH and WHF treatments in most measured parameters, resulting in overlapping clusters. Biplot analysis showed that DO and pH significantly affect the other parameters. This study demonstrated that DO has a positive value on WH and WHF treatments but not on control samples, indicating that both treatments could not increase DO.

On the other hand, control treatment increased the pH value. Meanwhile, both WH and WHF treatments tend to decrease it. Our study showed that the highly-contaminated leachate landfill, which causes alkaline conditions and lack of oxygen in irrigation systems, has been proven to be significantly neutralised through two treatments: WH and WHF. The combination treatment was not able to neutralise the pH of the sample compared to WH on several days of use, and it is due to the filter media, which makes it insignificant (Figure 3).

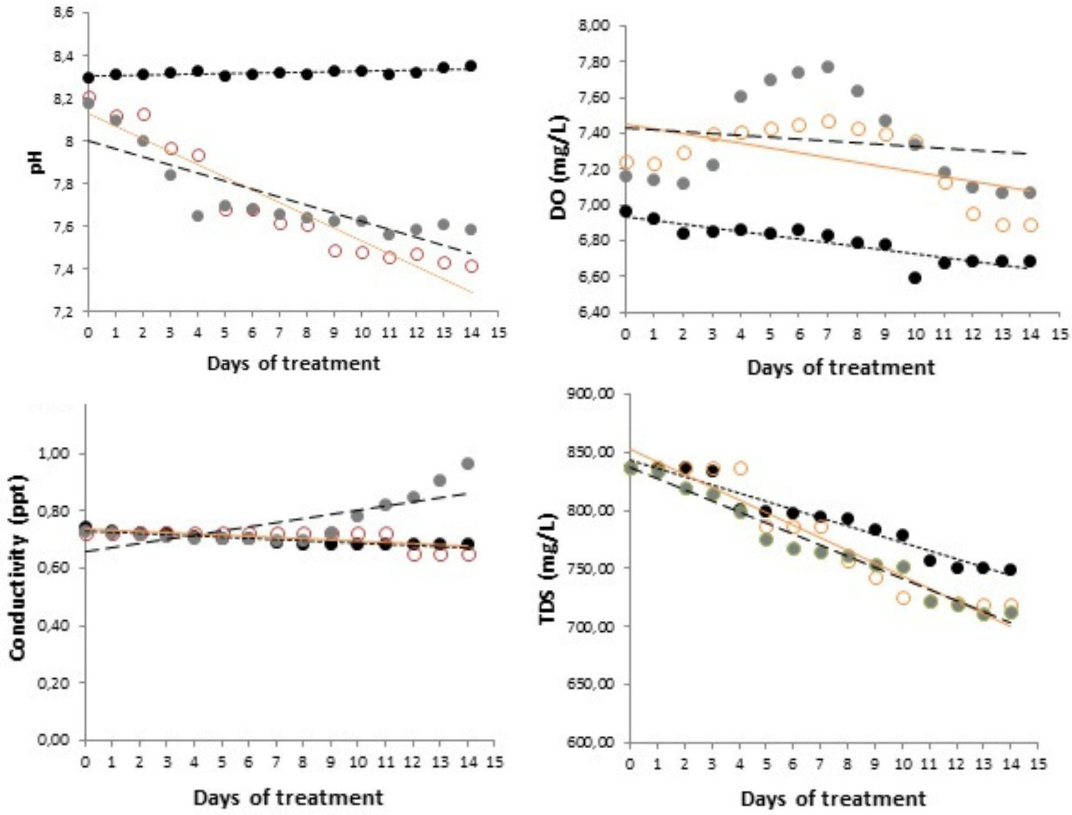

Figure 3. Scatter plot of the average pH measurement, DO, Conductivity, and TDS. Keys = black dot: Control; orange circle: WH; grey dot: WHF; smooth dashed line: Control trendlines; orange line: WH trendiness; rough dashed line: WHF trendlines. See methods for abbreviations

Table 1. Analysis of variance results on four parameters. Numbers followed by the same letter notation in the same column show that the results are not significantly different in the 5% DMRT test.

	Days of treatment														
	TDS			pH			OD			BOD			Conductivity		
	0	7	14	0	7	14	0	7	14	0	7	14	0	7	14
Control	8.30b	8.31b	8.35b	8.30b	8.31b	8.35b	6.97a	6.83a	6.48a	5.77a	5.43b	4.68b	1197a	1136.33a	1069.83b
WH	8.29b	7.53a	7.42a	8.29b	7.53a	7.42a	7.18a	7.43b	6.88a	6.05a	5.13b	4.48b	1196a	1123.33a	1026.83a
WHF	8.18a	7.65a	7.57a	8.18a	7.65a	7.57a	7.12a	7.75b	7.27a	5.62a	4.45a	3.75a	1195.83a	1092a	1017.83a
Sig.	0.019	0	0	0.019	0	0	0.454	0	0.476	0.122	0	0.015	0.419	0.611	0.034

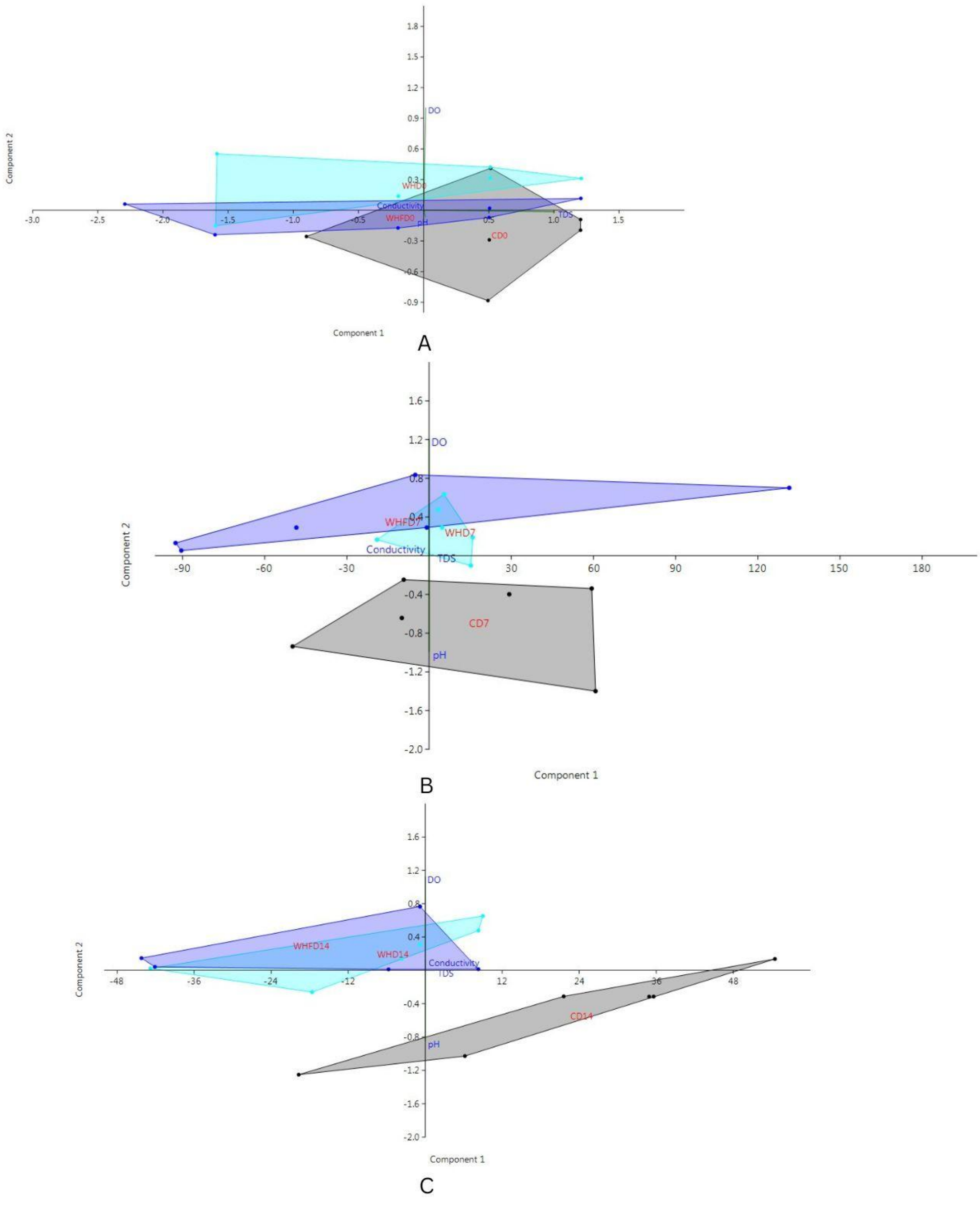

Figure 4. PCA and biplot graphs exhibit the resemblance between the treatment results as well as their interactions with physical parameters on days 0 (A), 7 (B), and 14 (C). Keys = CD0 : Control Day 0, WHD0 : Water Hyacinth Day 0, WHFD0: Water Hyacinth and Filter Day 0, CD7 : Control Day 7, WHD7 : Water Hyacinth Day 7, WHFD7 : Water Hyacinth and Filter Day 7, CD14 : Control Day 14, WHD14 : Water Hyacinth Day 14, WHFD14: Water Hyacinth and Filter Day 14

Discussion

The dramatic decrease in BOD indicates the level of activity of microorganisms in the decomposition of contamination (Khinanty and Retnaningdyah, 2017). The activity of microorganisms can modify organic matter into simpler compounds, which plants then utilized as nutrients, while WH will produce oxygen used in the metabolism of microorganisms (Widiyanti et al., 2020). Previous studies also noted that WH helped to reduce BOD in river waste by 8.96% for 14 days by using combination filters such as gravel, zeolite sand, and activated charcoal (Audiyanti et al., 2019). This reference is consistent with our observation that filter media is essential in reducing the contamination levels that microorganisms will use. Therefore, based on the

BOD measurements, we revealed that WHF is the most effective treatment. This evidence is linear with the previous research. WH can reduce the TDS value in wastewater up to 900 mg/L (Putra et al., 2017).

To emphasize the importance of incorporating WH in filtration systems, it should be noted that WH's unique biological properties contribute significantly to the reduction of various pollutants (Rezania et al., 2015). Its rapid growth rate and extensive root system provide a large surface area for absorption and adsorption of contaminants (Prasetyo et al., 2021), making it a cost-effective and environmentally sustainable option for water treatment. Furthermore, the plant's ability to thrive in a range of aquatic environments suggests its versatility in different water treatment scenarios. Therefore, integrating WH into existing filtration systems could potentially enhance their efficiency, offering a natural and effective solution for improving water quality on a larger scale.

Gravel provides a solid foundation and enhances overall filtration efficiency, zeolite emerges as the superior choice for comprehensive water detoxification and heavy metal removal, outperforming both charcoal and gravel in these specific areas (Midhun and Joseph 2019, Abdulredha et al., 2021). The selection of the best material ultimately depends on the specific requirements of the water filtration system and the nature of the contaminants present. The reduction in Biochemical Oxygen Demand (BOD) through specific filter components is a critical aspect of water treatment, primarily achieved by materials that can absorb contaminants or possess neutralizing functions. These materials, such as activated carbon or specialized resin beads, are chosen for their ability to efficiently trap organic matter and pollutants, which are the main contributors to high BOD levels (Assiddieq et al., 2017). Their high porosity and large surface area allow for effective absorption, while some may also chemically interact with pollutants, breaking them down or altering their composition to reduce their impact on BOD. This dual approach of physical absorption and chemical neutralization is essential in maintaining the health of aquatic ecosystems by preventing oxygen depletion and supporting aquatic life.

The increase in DO is supported by the presence of aquatic plants that photosynthesise and produce oxygen. An increase in DO indicates an improvement in water quality, and it is ready to use by other organisms. WH, as one of the aquatic plants, has an essential role in increasing DO in water (Liu et al., 2016). Microorganisms use dissolved oxygen for respiration, metabolism, and energy production. Oxygen is also essential to the degradation process of organic and inorganic materials (Ningrum et al., 2020).

The combination of activated charcoal, gravel, palm fibre, and water hyacinth biofilters in the process was effective in reducing the TDS value in water contaminated with sewage with a percentage decrease of 82.18% (Febrianda et al., 2018). Another study showed that the combination of activated charcoal, gravel, and zeolite sand filter media with a media thickness of 4 cm each reduced the TDS value to 209 mg/L (Elma et al., 2020). The decrease in dissolved substances in irrigation water samples is due to the ability of WH roots to retain particles and organic matter contained in polluted water (Widiyanti et al., 2020). The decrease in TDS in the sample indicates that the activity of microorganisms in the water will decompose organic and inorganic materials (Elisa and Irawanto, 2020). A decrease in the amount of organic matter can also occur due to the ability of an effective filter to absorb pollutant molecules (Liu et al., 2016).

Garbage that continues accumulating will cause methane fermentation due to anaerobic biological decomposition, which causes the pH to become alkaline (Angrianto et al., 2021). Vidyawati and Fitrihidajati (2019) showed that using WH as a phytoremediation agent could neutralise the pH of tofu liquid waste from 4.21 to 7.34. Phytoremediators can neutralise pH imbalances in a solution, both alkaline and acidic. This improvement makes the phytoremediator more effective than the progress provided by chemical or physical filters. Using a filter combination of gravel, sand, and WH can neutralise the pH of factory wastewater from 4 to 7 (Ilmannafian et al., 2020). The pH neutralisation process in the results of this research is due to the activity of microorganisms in decomposing organic matter and the photosynthetic activity carried out by plants to take dissolved CO_2 in the form of H_2CO_3 (Felani and Hamzah, 2007). Zeolite sand has microscopic and uniform pores and can only absorb molecules of the same diameter, so it is considered an ineffective combination in neutralising pH (Apriyani and Novrianti, 2020). Zeolite is potentially inactive in regulating anion-cation interactions (Delkash et al., 2015). In addition, the filter is considered ineffective, which is indicated by its ineffective neutralising pH, compared to a single WH as a fitoremediator.

Water Hyacinth is known for its remarkable effectiveness in neutralizing pH in water, primarily due to its unique biological and chemical properties (Rezania et al., 2015; Yunus et al., 2015). Biologically, the plant excels in phytoremediation, a process where it absorbs and accumulates contaminants from the water. This ability is partly due to the extensive and fibrous root system of Water Hyacinth, which not only absorbs pollutants but also provides a habitat for beneficial microorganisms. These microorganisms further contribute to purifying the water and stabilizing its pH (Ahmed et al., 2021). The plant's natural filtration process is enhanced by these biological interactions, making it more effective in neutralizing pH than many conventional filters.

Chemically, Water Hyacinth employs both absorption and adsorption mechanisms to treat water. The plant's tissues can absorb contaminants, while the surface of its roots can adsorb, or bind, various chemicals and metals from the water (Rezania et al., 2015). This dual action helps in effectively reducing toxicity and balancing the pH levels. Unlike other filters that might rely on purely mechanical or chemical processes, the Water Hyacinth integrates biological processes as well, making it a more holistic and environmentally friendly solution for water treatment. Its natural ability to adjust to different water conditions and its effectiveness in removing a wide range of pollutants make it a valuable tool in water purification systems.

Previous studies use a combination of zeolite sand filter media and water hyacinth plants, which effectively reduce waste's conductivity value (Sidek et al., 2018). A decrease in Conductivity is also recorded in the use of Water Hyacinth in several pollutants: nitrogen and phosphorus (Singh et al., 2022), Sewage (Dar et al., 2011), and the glass industry (Singh et al., 2022). Reduced pollutant, which in this case is expressed by the conductivity parameter, is evidence of the success of remediation (Irwan and Afdal, 2016; Apriyani and Novrianti, 2020).

The differences between treatments and the relationship with the parameters of bioremediation measured in this study were explained through PCA (Elshobary et al., 2020). Those differences have created significantly different clusters between control and treatments (Elshobary et al., 2020).

The study's findings have significant implications for improving irrigation water quality in areas facing similar pollution challenges. The successful combination of Water Hyacinth (*E. crassipes*) with filters like zeolite, charcoal, and gravel in reducing leachate contamination highlights a practical and sustainable approach to water treatment. The effectiveness of Water Hyacinth in absorbing heavy metals and organic pollutants, demonstrated in this study, suggests that it can be a vital component in bioremediation strategies for agricultural water systems. Implementing such natural filtration methods could enhance the quality of irrigation water, thereby supporting healthier crop growth and sustainable agricultural practices in regions affected by similar environmental contaminants. This approach not only addresses immediate water quality concerns but also contributes to the broader goal of sustainable environmental management. The combination treatment (Water Hyacinth and Filter) showed the most effective results in the remediation of leachate-contaminated water on most parameters. However, the filter is assumed to affect the failure of the combination treatment to neutralise pH significantly after Day 7, compared to the treatment with Water Hyacinth only. DO indicates a looming threat in the long-term experimental process that affects the treatment performance temporally.

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