

## Hydrological Assessment of A Water Hyacinth (*Eichhornia Crassipes*) Filtration System for Microplastic and Water Quality Improvement in The Krueng Aceh River

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**ABSTRAK:** Penelitian ini bertujuan untuk menilai kinerja hidrologis sistem filtrasi berbasis eceng gondok (*Eichhornia crassipes*) dalam mengurangi mikroplastik di Sungai Krueng Aceh. Pendekatan deskriptif kuantitatif digunakan dengan mengintegrasikan pengukuran lapangan, eksperimen laboratorium, dan simulasi hidrodinamika untuk meneliti bagaimana *E. crassipes* memodifikasi kecepatan aliran, waktu tinggal, dan retensi mikroplastik pada kondisi aliran terkontrol maupun alami. Hasil penelitian menunjukkan bahwa keberadaan eceng gondok secara signifikan menurunkan kecepatan aliran—dari 3,19 m/s menjadi 1,51 m/s pada pipa berdiameter 1 cm dan dari 0,75 m/s menjadi 0,27 m/s pada pipa berdiameter 2,5 cm—akibat peningkatan resistansi hidraulik oleh struktur akar dan batang. Penurunan kecepatan aliran ini meningkatkan waktu tinggal hidraulik, mendukung sedimentasi mikroplastik, dan proses biofiltrasi. Waktu tinggal yang lebih lama juga meningkatkan kapasitas sistem dalam retensi polutan dan perbaikan kualitas air. Kesimpulannya, sistem biofiltrasi berbasis eceng gondok efektif berfungsi sebagai regulator hidraulik alami, mendukung mitigasi mikroplastik secara berkelanjutan. Implementasinya di sepanjang tepi sungai dengan kepadatan tanaman terkontrol (25–50% dari luas aliran efektif) menawarkan solusi berbasis alam untuk rehabilitasi sungai dan pengelolaan sumber daya air terpadu di lingkungan perkotaan tropis. Temuan ini memberikan implikasi praktis dalam perancangan dan pengelolaan sistem filtrasi berbasis eceng gondok di sungai perkotaan tropis, khususnya melalui pengaturan kepadatan tanaman dan kondisi aliran untuk mengoptimalkan waktu tinggal hidraulik serta meningkatkan efisiensi penurunan mikroplastik.

**Kata kunci:** Mikroplastik, Filtrasi, Eceng Gondok, Hidrolika, Biofiltrasi

**ABSTRACT:** This study aims to assess the hydrological performance of a water hyacinth (*Eichhornia crassipes*)-based filtration system for microplastic removal in the Krueng Aceh River. A quantitative descriptive approach was employed, integrating field measurements, laboratory-scale experiments, and hydrodynamic simulations to investigate how *E. crassipes* modifies flow velocity, residence time, and microplastic retention under controlled and natural flow conditions. The results show that the presence of water hyacinth significantly reduces flow velocity—from 3.19 m/s to 1.51 m/s in 1 cm diameter pipes, and from 0.75 m/s to 0.27 m/s in 2.5 cm pipes—due to increased hydraulic resistance from root and stem structures. This reduction in flow velocity enhances hydraulic retention time, facilitating microplastic sedimentation and biofiltration processes. The extended residence time further improves the system's capacity for pollutant retention and overall water quality enhancement. In conclusion, the water hyacinth-based biofiltration system effectively functions as a natural hydraulic regulator, supporting sustainable microplastic mitigation. Its implementation along river margins with controlled plant density (25–50% of the effective flow area) offers a practical nature-based solution for river rehabilitation and integrated water resource management in tropical urban environments. These findings provide practical design and management insights for implementing water hyacinth-based filtration systems in tropical urban rivers, particularly by optimizing plant density and flow conditions to enhance hydraulic retention time and microplastic removal efficiency.

**Keywords:** Microplastic, Filtration, Water Hyacinth, Hydraulics, Biofiltration

### 1. INTRODUCTION

Microplastic pollution has emerged as one of the most pervasive and persistent environmental challenges of the 21st century, posing serious threats to aquatic ecosystems and human health [1,2].

Microplastics, defined as plastic particles smaller than 5 mm, originate from the breakdown of larger plastic waste and from synthetic fibers, cosmetics, and various industrial activities [2,3]. Due to their buoyancy, persistence, and small size, microplastics are easily transported through river systems and eventually accumulate in marine environments [3,4].

In Indonesia, microplastic contamination has become increasingly evident, especially in Aceh Province. Studies have reported the presence of microplastics in coastal and riverine ecosystems, including in coral reef waters of Krueng Raya, Aceh Besar [5], and in the sea surface waters of Banda Aceh City and Aceh Besar District [6]. Freshwater systems are also affected: the Krueng Aceh River, one of the region's primary freshwater sources, contains measurable microplastic concentrations, where ultrafiltration membranes have been tested for removal efficiency [7]. Improper waste management behaviors have been identified as a major contributor to riverine microplastic pollution [8]. Moreover, microplastics have been detected in fish harvested from estuarine mangrove forests of Banda Aceh, highlighting the risk of bioaccumulation and trophic transfer [9]. Microplastics from laboratory effluents and other sources have been shown to increase ecological and toxicological risks, underscoring their widespread environmental impact [15].

Despite these findings, most mitigation efforts in Aceh focus on physical or membrane-based technologies, which often entail high operational costs and maintenance complexity [7]. Nature-based solutions, such as phytoremediation using aquatic macrophytes—particularly *Eichhornia crassipes* (water hyacinth)—offer a sustainable, cost-effective alternative [10,11,12]. Water hyacinth is known for its rapid growth, high biomass productivity, and excellent capacity to remove suspended solids, heavy metals, organic pollutants, and microplastics from contaminated waters [9,10,11,13,14,21,23]. Integrating this plant into filtration systems has the potential to improve water quality while supporting ecological balance and hydrological functions in riverine environments [11,12,16,17,19].

Recent studies have highlighted the effectiveness of water hyacinth in trapping microplastics and retaining river plastics, as well as its role in ecological restoration and wastewater treatment [10–14,16–20,22]. In addition, water hyacinth has been proposed as a component of constructed wetlands and hydroponic systems for improving water quality in urban and rural watersheds [19,21,23,24]. These findings suggest that incorporating water hyacinth into microplastic

filtration systems could provide a low-cost, environmentally friendly solution for river rehabilitation in tropical urban areas. However, most previous studies primarily focus on the pollutant removal capability of water hyacinth or its application in wastewater treatment systems, with limited attention to its hydrological role in modifying flow dynamics and enhancing microplastic retention in river filtration systems.

Therefore, the novelty of this research lies in integrating water hyacinth into a filtration system while simultaneously evaluating its hydrological performance, particularly its influence on flow velocity, hydraulic residence time, and microplastic retention efficiency under controlled experimental conditions. This approach provides a more comprehensive understanding of how aquatic macrophytes can function not only as biological filters but also as natural hydraulic regulators in riverine environments.

This study assesses the hydrological performance of a water hyacinth-based filtration system for microplastic removal in the Krueng Aceh River. The objectives are to evaluate its effectiveness in reducing microplastic concentrations and to analyze its influence on water quality parameters. The findings are expected to contribute to the development of sustainable, nature-based filtration systems that support river rehabilitation and water resource management in tropical urban regions.

## 2. MATERIALS AND METHODS

This study employed an experimental, quantitative, descriptive design to evaluate the hydraulic behavior and filtration efficiency of *Eichhornia crassipes* (water hyacinth) in reducing microplastic concentrations in the Krueng Aceh River. The research combined field measurements, laboratory experiments, and hydrodynamic simulations to determine how the presence of *E. crassipes* affects flow velocity, residence time, and microplastic retention under controlled and natural flow conditions.

### 2.1 Research Design

The overall research workflow consisted of four main stages: (1) field data collection and water sampling from the Krueng Aceh River, (2) preparation of laboratory-scale filtration experiments using water hyacinth, (3) hydraulic measurements including discharge and flow velocity under controlled conditions, and (4) data analysis to evaluate the influence of water hyacinth on hydraulic behavior and microplastic retention efficiency.

In addition, microplastic analysis was conducted to quantify particle abundance and evaluate removal efficiency before and after the filtration process.

**2.2 Study Area and Duration**

The research was conducted along the Krueng Aceh River, which flows through Banda Aceh City and Aceh Besar Regency, Indonesia. Sampling points were selected at three main locations representing different pollution levels: upstream, midstream, and downstream. The experimental and analytical work was carried out over approximately 4 months, including field surveys, water sampling, filtration experiments, and data interpretation.

At each sampling location, river water samples were collected using sterile sampling bottles and transported to the laboratory for further experimental analysis. The sampling locations were selected to represent variations in anthropogenic activities, including residential areas, urban drainage inputs, and downstream accumulation zones.

A total of 6 water samples (3 sampling points × 2 conditions: before and after filtration) were analyzed for microplastic content. Each sample was processed in triplicate to ensure analytical accuracy and reproducibility.

**2.3 Hydraulic Calculation in Microplastic Filtration**

The hydraulic assessment was based on the fundamental principles of open channel flow and pollutant transport in aquatic systems. The main parameters analyzed include flow discharge, cross-sectional area, and flow velocity, calculated using the following equations:

$$Q = \frac{V}{t} \tag{1}$$

$$A = \frac{\pi \cdot d^2}{4} \tag{2}$$

$$v = \frac{Q}{A} \tag{3}$$

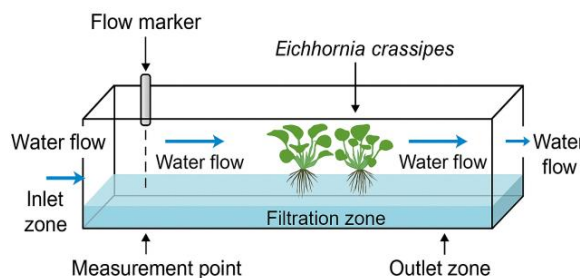
- v = flow velocity (m/s)
- Q = discharge (m<sup>3</sup>/s)
- A = cross-sectional area (m<sup>2</sup>)
- V = water volume (m<sup>3</sup>)
- t = time (s)
- d = diameter of the pipe or channel (m)
- π ≈ 3.1416

These parameters were used to compare hydraulic behavior under two conditions: with and without water hyacinth. The flow velocity and residence time were analyzed to determine the extent to which *E. crassipes* influences sedimentation, turbulence, and particle capture efficiency in the water column. Hydraulic residence time was estimated by dividing the effective water volume within the filtration system by the measured discharge rate. This parameter was used to evaluate the duration of interaction between microplastic particles and the root structures of water hyacinth within the filtration zone.

**2.4 Experimental Setup**

In the laboratory, the experimental setup was designed to simulate the flow and filtration behavior of the Krueng Aceh River under controlled hydraulic conditions. A rectangular flow tank made of transparent acrylic was constructed to represent a small-scale open channel system, as shown in Figure 1. The tank consisted of three zones:

1. Inlet zone – where microplastic-contaminated water was introduced,
2. Filtration zone – containing *Eichhornia crassipes* (water hyacinth) or left empty for control experiments, and
3. Outlet zone – for effluent collection and measurement.



**Figure 1.** Experimental Setup



**Figure 2.** Laboratory testing process.

The flow tank had a controlled inlet-discharge system supplied by a pump to maintain consistent hydraulic conditions during each experimental run. The water hyacinth plants used in the filtration zone were selected with relatively similar sizes and root lengths to ensure uniform experimental conditions. Before the experiment, the plants were acclimatized in clean water for 24 hours to remove attached debris or contaminants.

The experiment involved two primary test conditions:

- Condition 1: Flow without *Eichhornia crassipes* (control)
- Condition 2: Flow with *Eichhornia crassipes* coverage (treatment)

The laboratory tests were conducted to measure flow velocity and compare the hydraulic behavior between the two conditions. Flow velocity was determined by recording the travel time of water over a fixed distance using flow markers. Discharge (Q) and velocity (v) were calculated based on the measured flow rate and cross-sectional area using the equations described earlier. Figure 2 illustrates the experimental procedure, showing the flow tank setup, the placement of *Eichhornia crassipes* in the filtration zone, and measurement points for velocity and sample collection at the inlet and outlet.

Each experimental condition was repeated three times to ensure data consistency and reliability. Water samples were collected from both the inlet and outlet zones during each trial to evaluate changes in microplastic concentration and flow characteristics.

Microplastic analysis was performed using a filtration-and-visual-identification method. Water samples were first filtered using a vacuum filtration system with filter paper (pore size 0.45  $\mu\text{m}$ ) to retain microplastic particles. The retained particles were then observed and counted under a stereomicroscope based on their physical characteristics, such as shape (fiber, fragment, film), color, and size. Microplastic abundance was expressed as the number of particles per unit volume (particles/L).

To ensure data reliability, procedural blanks were used to minimize contamination, and all equipment was rinsed with distilled water before use. The filtration system's removal efficiency was calculated by comparing microplastic concentrations before and after treatment using a percentage reduction approach.

The collected data were then analyzed descriptively and comparatively to determine the influence of water hyacinth on hydraulic resistance,

turbulence reduction, and microplastic retention efficiency. The results from both conditions were then analyzed to evaluate how the presence of *Eichhornia crassipes* influenced flow resistance, turbulence reduction, and microplastic retention efficiency

### 3. RESULTS AND DISCUSSIONS

To determine the flow characteristics in the test channel, measurements were conducted of the volume of water flowing over a given time for different pipe diameters.

#### 3.1 Calculation of Flow Rate and Velocity

The obtained data were then used to calculate the discharge (Q) and flow velocity (v) using basic hydraulic equations. The calculation results are presented in Table 1.

Based on the data in Table 1, the discharge (Q) and flow velocity (v) are influenced by the pipe diameter and the volume of water flowing. In the first test, with a pipe diameter of 0.01 m and a flow time of 217 seconds, the discharge was 0.0001189  $\text{m}^3/\text{s}$ , corresponding to a velocity of 1.514 m/s. This value increased significantly in the third test, which used the same diameter but a shorter flow time (103 seconds), resulting in a discharge of 0.0002506  $\text{m}^3/\text{s}$  and a velocity of 3.191 m/s.

Meanwhile, for pipes with larger diameters (0.025 m), the discharge and velocity showed different results. In the second test, with a flow time of 97 seconds, the discharge reached 0.0001331  $\text{m}^3/\text{s}$ , and the velocity was 0.271 m/s. However, in the fourth test, with a shorter flow time (35 seconds), the discharge increased to 0.000369  $\text{m}^3/\text{s}$  and the velocity reached 0.751 m/s.

These differences indicate that the pipe diameter and flow duration play an important role in determining the fluid's discharge and velocity. The larger the pipe diameter and the shorter the flow time, the higher the discharge and velocity values obtained. This result is consistent with the principle of flow continuity, which states that discharge is directly proportional to the cross-sectional area and the flow velocity.

#### 3.2 Comparison of Basic Data

Before analyzing the hydraulic performance of the microplastic filtration system, a comparison of the basic flow data was conducted, as presented in Table 2. This table provides the initial measurement parameters, including water volume, flow time, pipe diameter, and the physical shape of the container or hose used during testing. From Table 2, it can be seen

that the experiments were carried out using two cylindrical configurations—small and large—with pipe diameters of 1 cm and 2.5 cm, respectively. The volume of water used in the small-cylinder tests was 25.81 L, while the large-cylinder tests used 12.91 L.

The time required for water to pass through each configuration varied significantly with pipe diameter. For the small cylinder (1 cm diameter), the flow times were longer, reaching 217 seconds in the first trial and 103 seconds in the third. In contrast, the larger cylinder (2.5 cm diameter) produced shorter flow durations of 97 seconds and 35 seconds in the second and fourth trials, respectively.

These differences suggest that the larger pipe diameter facilitates higher flow rates by providing a greater cross-sectional area, allowing water to move more freely. The smaller cylinder, on the other hand, produces a more constricted flow with longer discharge times. This variation in hydraulic characteristics forms the basis for further analysis of flow behavior with and without *Eichhornia crassipes* (water hyacinth) in the filtration system.

**3.3 Calculation Results**

Following the basic data comparison, hydraulic parameters such as discharge (Q), velocity (v), and cross-sectional area (A) were calculated to determine the flow characteristics under different test conditions. The results are presented in Table 3.

As shown in Table 3, the discharge values range between 0.000119 m<sup>3</sup>/s and 0.000369 m<sup>3</sup>/s, while the

flow velocity varies from 0.27 m/s to 3.19 m/s. These differences are strongly influenced by variation in cross-sectional area and flow duration across tests.

The highest velocity (3.19 m/s) occurred in the third trial, which used a smaller diameter pipe (0.01 m). This indicates that a narrower cross-section produces faster flow due to higher pressure buildup. Conversely, the lowest velocity (0.27 m/s) was recorded in the second trial, which used a larger diameter (0.025 m), resulting in slower flow movement.

The relationship between discharge and velocity follows the equation  $Q = A \times v$ , where an increase in cross-sectional area with constant discharge causes a decrease in flow velocity, and vice versa. These findings confirm that pipe diameter and cross-sectional geometry play significant roles in determining flow dynamics and the effectiveness of microplastic filtration using *Eichhornia crassipes*.

**3.4 Flow Characteristic Comparison**

Table 4 presents a comparative analysis between flow conditions in calculations 1–2 and 3–4, emphasizing the influence of measurement duration, pipe diameter, and resulting hydraulic parameters such as discharge and velocity.

From the analysis, it can be observed that calculations 1 and 2 exhibit a longer measurement time (97–217 s) and generally slower, more stable flow characteristics, primarily due to the larger pipe

**Table 1.** Calculation of Flow Rate and Velocity

Count	Volume (L)	Volume (m <sup>3</sup> )	Time (s)	Diameter (cm)	Diameter (m)	Cross-sectional area (m <sup>2</sup> )	Discharge (m <sup>3</sup> /s)	Velocity (m/s)
1	25,81	0,02581	217	1	0,01	0,00007854	0,00011894	1,514388747
2	12,91	0,01291	97	2,5	0,025	0,000490875	0,000133093	0,271133758
3	25,81	0,02581	103	1	0,01	0,00007854	0,000250583	3,19050833
4	12,91	0,01291	35	2,5	0,025	0,000490875	0,000368857	0,751427844

**Table 2.** Comparison of Basic Data

Count	Volume (L)	Time (s)	Diameter (cm)	Container/Pipe Shape
1	25,81	217	1	Small cylinder
2	12,91	97	2,5	Large cylinder
3	25,81	103	1	Small cylinder
4	12,91	35	2,5	Large cylinder

**Table 3.** Calculation Results

Count	Discharge (m <sup>3</sup> /s)	Velocity (m/s)	Cross-sectional Area (m <sup>2</sup> )
1	0,000119	1,51	0,000078

2	0,000133	0,27	0,000491
3	0,000251	3,19	0,000078
4	0,000369	0,75	0,000491

**Table 4.** Flow Characteristic Comparison

Aspect	Counts 1 & 2	Counts 3 & 4
Measurement Time	Longer (97–217 s)	Shorter (35–103 s)
Pipe Diameter	Count 1 small, Count 2 large	Count 3 small, Count 4 large
Flow Discharge	$1.19\text{--}1.33 \times 10^{-4} \text{ m}^3/\text{s}$	$2.51\text{--}3.69 \times 10^{-4} \text{ m}^3/\text{s}$
Flow Velocity	0.27–1.51 m/s	0.75–3.19 m/s
Flow Characteristics	Slower and more stable	Faster and more intense

diameter and lower flow pressure. The resulting flow velocity ranges from 0.27 to 1.51 m/s, with discharge values between  $1.19 \times 10^{-4}$  and  $1.33 \times 10^{-4} \text{ m}^3/\text{s}$ .

In contrast, calculations 3 and 4 demonstrate shorter measurement times (35–103 s) and faster, stronger flow, influenced by the smaller pipe diameter and reduced residence time. The recorded discharge ranges from  $2.51 \times 10^{-4}$  to  $3.69 \times 10^{-4} \text{ m}^3/\text{s}$ , with corresponding velocities between 0.75 and 3.19 m/s.

The comparison shows that pipe diameter and flow duration are the dominant factors determining hydraulic behavior. A smaller cross-section results in higher velocity and discharge due to increased flow pressure, while larger diameters promote slower, more laminar flow.

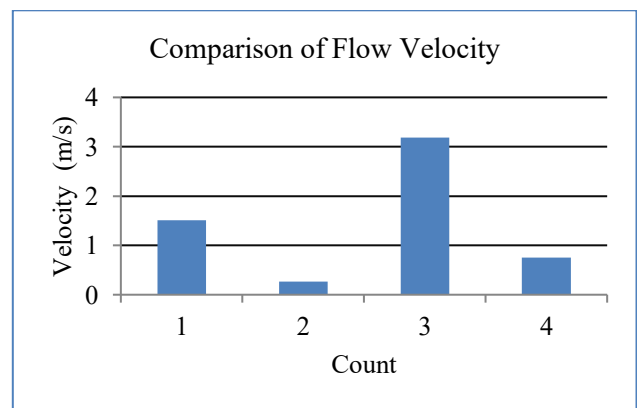
These differences are crucial for understanding the hydraulic behavior of the microplastic filtration system employing *Eichhornia crassipes*, as they indicate the optimal flow conditions under which the plants can effectively trap and filter suspended microplastic particles in the Krueng Aceh River.

**3.5 Flow Velocity of Conditions With and Without Water Hyacinth**

Table 5 presents the results of flow velocity measurements under two conditions: with and without the presence of water hyacinth (*Eichhornia crassipes*). The comparison evaluates how aquatic vegetation affects flow dynamics and hydraulic performance in the microplastic filtration system. The results show that under water hyacinth conditions (calculations 1 and 2), the flow velocity ranges from 0.27 to 1.51 m/s, with a discharge of 0.000119–0.000133  $\text{m}^3/\text{s}$ . This relatively lower velocity indicates that the presence of water hyacinth increases flow resistance, thereby reducing the overall flow rate. The plants act as a natural physical barrier, disrupting flow momentum and promoting

sedimentation or particle capture, which enhances the potential for microplastic retention.

In contrast, under conditions without water hyacinth (calculations 3 and 4), the velocity increases significantly, ranging from 0.75 to 3.19 m/s, with discharge values of 0.000251–0.000369  $\text{m}^3/\text{s}$ . The absence of vegetation reduces flow resistance, resulting in faster and more turbulent water movement. Although higher flow velocities may increase water transport efficiency, they reduce the retention time necessary for effective filtration and microplastic trapping.



**Figure 3.** Comparison of Flow Velocity Showing the Decrease in Flow Speed Before and After Passing Through the Water Hyacinth Filtration Zone

Overall, the comparison suggests that the inclusion of water hyacinth is vital for stabilizing and moderating hydraulic conditions, enabling more efficient sedimentation and filtration processes within the microplastic removal system in the Krueng Aceh River.

Figure 3 illustrates the hydraulic performance of the water hyacinth (*Eichhornia crassipes*) filtration system in the Krueng Aceh River, highlighting the

gradual decrease in flow velocity observed across four experimental stages. The data reveal a systematic reduction in velocity from approximately 3.5 m/s under untreated flow conditions to about 0.5 m/s after passing through the water hyacinth filtration system. Intermediate measurements of 2.5 m/s and 1.5 m/s represent transitional flow stages influenced by the progressive density of the plant roots and biomass.

This decline in flow velocity reflects the increased hydraulic resistance generated by the water hyacinth's extensive root network, which disrupts momentum and extends the water's residence time. Such hydraulic conditions are beneficial for microplastic removal, as they enhance sedimentation of suspended particles and increase the likelihood of microplastic entrapment within the root structure. In addition, the slower flow promotes greater interaction between the water and plant surfaces, supporting adsorption of fine particles and dissolved contaminants.

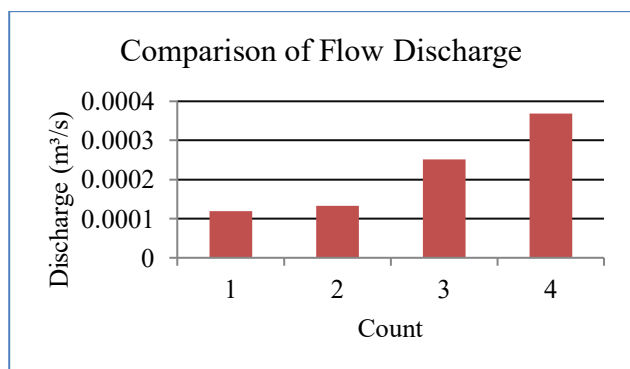
The observed hydraulic behavior indicates that the water hyacinth system not only reduces flow velocity but also establishes a stable environment for physical filtration and biological treatment processes. These characteristics confirm its effectiveness as a nature-based filtration system for mitigating

microplastic pollution and improving water quality in the Krueng Aceh River.

Figure 4 presents the variation in flow discharge measured at different stages of the filtration experiment. The figure illustrates how discharge values gradually decrease as water passes through the water hyacinth zone, indicating the influence of plant biomass on hydraulic resistance and flow regulation. This flow-rate comparison demonstrates the variation in discharge observed at different monitoring points within the water hyacinth (*Eichhornia crassipes*) filtration system designed for the Krueng Aceh River. The measured discharge rates, ranging from 0 to 0.0004 m<sup>3</sup>/s, with intermediate values of 0.00035, 0.0003, 0.00025, 0.0002, 0.00015, 0.0001, and 0.00005 m<sup>3</sup>/s, reflect the progressive influence of the plant biomass on the hydraulic performance of the system. The gradual reduction in discharge along the filtration path indicates an increase in hydraulic resistance due to the dense root network and biomass of water hyacinth. This resistance plays an essential role in moderating flow velocity, thereby extending the hydraulic retention time within the system. A longer retention period provides greater opportunity for sedimentation of suspended solids and entrapment of microplastic particles, while also facilitating pollutant adsorption onto root surfaces.

**Table 5.** Flow Velocity of Conditions With and Without Water Hyacinth

Count	Flow Condition	Volume (L)	Time (s)	Diameter (cm)	Discharge (m <sup>3</sup> /s)	Velocity (m/s)
1	With Water Hyacinth	25,81	217	1	0,000119	1,51
2	With Water Hyacinth	12,91	97	2,5	0,000133	0,27
3	Without Water Hyacinth	25,81	103	1	0,000251	3,19
4	Without Water Hyacinth	12,91	35	2,5	0,000369	0,75



**Figure 4.** Comparison of Flow Discharge at Different Experimental Stages Showing the Influence of Water Hyacinth Biomass on Flow Reduction

These findings align with the study's overall objective to evaluate the hydraulic performance of a water hyacinth-based microplastic filtration system. The observed flow-rate behavior supports earlier results showing that reduced velocity and discharge enhance the filtration capacity of aquatic plants. Consequently, the system demonstrates strong potential as a sustainable, eco-friendly solution to improve water quality and mitigate microplastic pollution in the Krueng Aceh River.

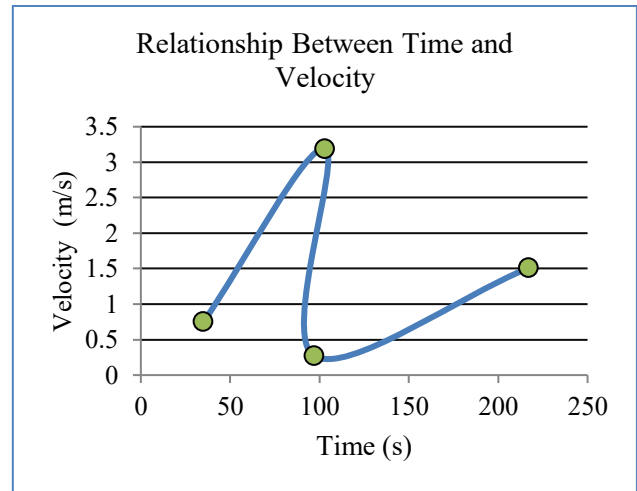
Figure 5 illustrates the relationship between observation time and flow velocity within the experimental system. The graph shows that flow

velocity gradually decreases over time as hydraulic resistance increases due to the presence of water hyacinth roots and biomass. The temporal variation indicates a consistent decline in velocity from approximately 3.5 m/s to 0.5 m/s over a 250-second observation period. This gradual decrease reflects the increasing hydraulic resistance generated by the dense root structure and biomass of *Eichhornia crassipes* as the filtration process progresses.

The inverse relationship between time and flow velocity highlights the crucial role of hydraulic dynamics in enhancing the system’s treatment performance. As the flow slows, the hydraulic retention time increases, allowing more effective sedimentation of suspended particles and a greater potential for microplastic capture within the plant’s root network. Furthermore, the extended contact duration between the flowing water and the biological filtration medium supports adsorption and phytoremediation of dissolved contaminants.

These results reinforce the findings of previous analyses and align with the study’s main objective—to assess the hydraulic performance of the water hyacinth filtration system for microplastic removal in the Krueng Aceh River. The observed temporal attenuation of flow confirms that the system can

maintain stable hydrodynamic conditions conducive to both physical and biological treatment processes. This dynamic behavior demonstrates the potential of water hyacinth as an effective nature-based solution to improve water quality and mitigate microplastic pollution in riverine environments.



**Figure 5.** Relationship Between Observation Time and Flow Velocity in the Water Hyacinth Filtration System

**Table 6.** Comparative Analysis of Flow Characteristics With and Without Water Hyacinth

Observed Aspect	With Water Hyacinth (Cases 1–2)	Without Water Hyacinth (Cases 3–4)
Water Medium Condition	Water partially covered by hyacinth plants	Water flows freely without obstruction
Flow Discharge (Q)	$1.19\text{--}1.33 \times 10^{-4} \text{ m}^3/\text{s}$	$2.51\text{--}3.69 \times 10^{-4} \text{ m}^3/\text{s}$
Velocity (v)	0.27–1.51 m/s	0.75–3.19 m/s
Flow Duration	Longer (97–217 s)	Shorter (35–103 s)
Resistance Effect	High resistance due to plant roots and stems	No resistance, smooth flow

Table 6 provides a comparative analysis of the hydraulic characteristics and flow behaviors between systems with and without water hyacinth (*Eichhornia crassipes*), corresponding to measurements 1–2 and 3–4, respectively. The results reveal that the introduction of water hyacinth notably reduced discharge rates from  $2.51\text{--}3.69 \times 10^{-4} \text{ m}^3/\text{s}$  in the control setup to  $1.19\text{--}1.33 \times 10^{-4} \text{ m}^3/\text{s}$  in the vegetated system. This reduction demonstrates the hydraulic influence of the plant, where its dense root and stem structure increases resistance and effectively moderates flow dynamics.

Similarly, the flow velocity decreased significantly in the presence of water hyacinth,

ranging from 0.27 to 1.51 m/s compared to 0.75 to 3.19 m/s without vegetation. This attenuation reflects the system’s capacity to slow water movement, a critical factor for enhancing hydraulic retention time and promoting more efficient pollutant removal. In fact, the retention time increased markedly from 35–103 seconds in the open channel to 97–217 seconds in the water hyacinth system, indicating a longer interaction period between water and the biofiltration media.

Visual observations support these quantitative results: the vegetated system displayed slower, more stable flow with partial surface coverage by plants, while the control system exhibited fast, unobstructed

movement. These outcomes align closely with the study's main objective: analyzing the hydraulic performance of a water hyacinth filtration system for microplastic mitigation in the Krueng Aceh River.

The findings confirm that water hyacinth not only modifies hydraulic conditions but also optimizes sedimentation, filtration, and pollutant retention, reinforcing its potential as a sustainable, nature-based approach for improving river water quality.

#### 4. CONCLUSIONS

The results of this study confirm that water hyacinth (*Eichhornia crassipes*) effectively decreases flow velocity by introducing hydraulic resistance through its dense root and stem structures. In controlled laboratory conditions, the flow velocity in 1 cm diameter pipes decreased from 3.19 m/s to 1.51 m/s, while in 2.5 cm diameter pipes it dropped from 0.75 m/s to 0.27 m/s. These findings are consistent with basic fluid mechanics principles, in which increased flow resistance and reduced cross-sectional area lead to lower velocities and longer hydraulic residence time. This hydraulic adjustment enhances the potential for sedimentation and microplastic entrapment, demonstrating that water hyacinth functions as an effective natural flow regulator and biofiltration medium.

For real-world applications, the deployment of water hyacinth should be strategically managed along

riverbanks, covering approximately 25–50% of the effective flow area to reduce velocity without impeding the main channel. Periodic harvesting and maintenance are necessary to prevent overgrowth and maintain system performance. Continuous monitoring of discharge, flow velocity, and water quality indicators is also crucial to ensure stable filtration efficiency.

Future studies are encouraged to explore different plant densities, assess pre- and post-filtration microplastic concentrations, and use hydraulic modeling tools such as HEC-RAS to simulate flow behavior. Such investigations will provide a more comprehensive understanding of system optimization and scalability. Overall, this research reinforces the potential of water hyacinth-based filtration systems as a sustainable, eco-friendly strategy to improve hydraulic performance and mitigate microplastic pollution in riverine environments, particularly in the Krueng Aceh River.

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