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ORIGINAL PAPER

Lake Water Treatment Using Green Wall System: Effects of Filter Media Ratio and Lake Water Flow Rate on Treatment Performance

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Abstract

Lake water pollution has become a growing concern over the years. Therefore, alternative water treatment solutions are needed to address this issue. Green wall is considered as a potential alternative to treat lake water. However, the treatment performance of filtering media in removing lake water pollutants is unknown. Previous studies suggested that coir and perlite could be the potential filter media for the green wall system. Hence, this research studied the pollutant removal efficiency of various ratios of combined media. Thereafter, the treatment performance was evaluated with different lake water flow rate. The result showed that the 3:1 coir-to-perlite combined media ratio achieved the highest chemical oxygen demand (COD), total suspended solid (TSS) and turbidity removal with constant hydraulic load. This suggested that coir played an important role in governing both physico-chemical and biological processes due to the impact of retention time on the removal. It was found that the removal of pollutants was insignificant when the lake water flow rate is higher and lower than 28 L/h. This study also indicated that the lake water flowrate of 28 L/h managed to achieve consistent removal in COD, turbidity, TSS and TN with 53%, 54%, 41% and 52% removal, respectively.

Keywords Green wall · Coir · Perlite · Lake water · Water treatment · Flow rate

Introduction

In recent years, multiple studies had shown that human activities such as agriculture, industrialisation, sewage disposal and illegal mining resulted in the lake water quality deterioration [1, 2]. The effluent of these activities carries contaminants that consists of heavy metals, phosphorus and nitrogen [3]. Nitrogen and phosphorus content are important nutrients for the aquatic plants in freshwater. However, excess amount of these nutrients can cause problems like oxygen depletion, nutrient enrichment and diseases to the existing aquatic system. Therefore, the amount of these pollutant in the lake water quality must be controlled. To date, many water treatment technologies have been developed to reduce water pollution. Biofiltration system is identified as one of the cheapest, practical, low cost and environmentally friendly solution for wastewater treatment. Among the biofilters, constructed wetlands are commonly used to treat various kinds of wastewater sources due to its capability in removing organic pollutants and suspended solid if well-maintained [4, 5]. Nowadays, the wetland technologies are available even in the urban context. These treatment systems used to be out of favour, mainly due to space limitation for placement. However, the technology has not yet reached a deep integration into urban areas, although there has been a quick development over the last two decades [6]. Moreover, these systems do not complement with the overall aesthetic of the surroundings due to the limitation of the plant species.

With the growing attention of adopting green infrastructures in urban areas, green wall is one of the green technologies that can be implemented alongside to adopt the water treatment process of constructed wetlands for sustainable development [7]. Green walls are vertical vegetated systems made of plants that are grown in media-filled planter boxes. These systems save up horizontal space due to their vertical structure. Not only were they frequently used as aesthetic features in cities but also provide multiple benefits such as thermal and sound insulation, temperature regulations, air

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purification and building energy saving [8–10]. Despite the benefits, its application is limited by the high water consumption of the system. However, if the water source can be switched to other sources like lake water, it can be transformed to a low-cost and better sustainable solution for water treatment. This would eliminate their needs of constant irrigation. Additionally, the excessive nutrient recovered from the polluted lake water can be beneficial to plant growth. Nowadays, the potential of converting green walls into water treatment system has been widely investigated. A few studies were conducted to identify the ability of green wall in treating greywater. For example, a case study has described a pilot installation of a green wall treating greywater from an office building in Pune [11]. Another example includes a study conducted by Fowdar (2017), who has reproduced a living wall system to study its operational and design aspects such as filling materials and inflow concentration [12]. Moreover, another laboratory study examined various growing media for green wall to identify the underlying pollutant removal process and treatment capacity of the system [13]. Despite green wall being tested in greywater treatment, its ability in treating lake water is yet to be investigated. The different types of water and target of treatment efficiencies are worth investigating. Additionally, further developments are still required to achieve the standard of existing water treatment system. Thus, the characteristics of the system have to be investigated to understand its treatment capability towards lake water. Previous studies that also pointed out further exploration on the green wall elements are needed to further optimize its engineering design. Among the parameters, the selection of filter media is crucial as it relates to the treatment efficiency and clogging issues of the wall. Multiple studies also highlighted the importance and effectiveness of filter media in removing excessive nutrients such as nitrogen, phosphorus and metals in biofiltration system [14–16]. However, some media in these systems, such as sand and wood particulate might not be suited for the green wall. Due to its vertical structure, the media is preferred to be light weighted to reduce the load on its supporting structure. Furthermore, conventional biofilters are usually constructed with a saturated zone to increase the retention time of water. This design allows the growing plants to contact with water for a longer period, which promotes the pollutant removal process to happen [13]. However, it is difficult to apply this concept on green wall as the retained water will increase the load of the system. Therefore, the pollutant removal performance of conventional biofilters is usually better than the green wall systems.

To date, light-weighted materials such as perlite, coir, lightweight expanded clay aggregate (LECA) and cork granulates are commonly used in biofilters. The physical properties and water retention capacities of these media are well understood. Generally, cork granulates provide good pollutant removal efficiency due to its great absorption capacity. Studies have pointed out the capability of this material in removing pollutants in constructed wetlands [17]. However, there is insufficient scientific review for the commercial green wall system to adopt this media. As the commercial green walls are not used for water treatment, this media might not have the same effect as it functions in constructed wetland. Besides, LECA, coir and perlite were also tested for their performance in greywater treatment by a group of researchers [13]. LECA and perlite have similar physical properties. They are great in retaining pollutants while infertile to bacteria and pathogens, which makes it suitable for plant growth. Additionally, these media have high porosity, which greatly reduces the clogging effect of the system. From the study, the overall performance of perlite is better than LECA in terms of total suspended solid (TSS) removal. Nevertheless, the perlite has low removal performance due to its high water infiltration rate. In contrast, the study shows that coir has achieved the highest removal performance among the media that had been studied. However, its treatment performance is hindered by its poor hydraulic performance because it is very susceptible to physical clogging due to its high density. [13].

Therefore, this study aims to combine coir and perlite to overcome the shortcomings of these filtering media. It was anticipated that the combination of media could provide better performance for lake water treatment. Thus, one of the aims of this research is to find out the suitable ratio of coir and perlite that provides high lake water treatment performance using the green wall system. To reflect the characteristics of the green wall, a lab scale recirculating green wall filtration system was built. As lake water was continuously recirculated in the system, the flow rate applied to the system could potentially affect its treatment performance. Hence, the study also aims to investigate the effect of applying various lake water flow rate to the green wall system.

Materials and Methods

Research Materials

Six parameters were studied in this research, which include chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), total suspended solid (TSS), turbidity and pH. The analysis for COD, TN and TP was tested using chemical test kits from Merck with the detection range of 3–1500 mg/L-COD, 0.5–5 mg/L-P and 1–16 mg/L-N, respectively. TSS was measured with spectrophotometer (SV-Prove 300). pH values were recorded using pH metre and the turbidity was determined using turbidity metre. For the green wall filtration system, the filter media (e.g. coir and perlite) were purchased from local garden nursery and *Epipremnum aureum* was chosen to be the growing plant in each of the pot in the green wall filtration system.

Experimental Setup

The constructed green wall system consists of four rows of media containers. Each row consists of five filter medium containers and arranged vertically. Hence, a total of 20 containers were constructed. The height of each container was fixed at 125 mm, allocating 100 mm filter media and 25 mm free board for detention of water. The bottom of the containers has a small opening, allowing the water to flow from upper container to the lower container. Plastic meshes were placed at the bottom of the container to hold the media in place. The system is 1.7 m in height to ease the maintenance work during the experiment. The configuration of the constructed green wall filtration system is shown in Fig. 1.

The constructed green wall system consists of lake water storage tank, water pump (40W, 1900 L/H) and valve. To perform lake water treatment, the lake water in the storage tank was pumped to the top of the system. A valve was installed along the pipeline to control the lake water flow rate of the system. The lake water that released from the top passed through the media containers layer by layer vertically and falls into the temporary water reservoir. The purpose of adding a reservoir is to reduce the water splashing during the treatment process. Also, it provides convenience for sampling collection. The temporary water reservoir was connected to an outlet pipe, allowing the water returns to the tank, thus creating a water recirculating system. The treated water that passed through the last layer of media container was then collected for water quality analysis. To reflect the characteristic of the conventional green wall, the constructed green wall system was vegetated. *Epipremnum aureum* was chosen to be planted in the system due to its availability in Malaysia. Moreover, this plant can adapt to temperature, tropic climatic conditions and be able to survive for more than 2 months without nutrients [18]. Study also showed that *Epipremnum aureum* was previously used for wastewater treatment, which makes it a suitable plant candidate for the system [18]. The green wall system was set up in a semi open-air area with sufficient natural sunshine, but with impermeable roof to avoid heavy rainfalls that could affect the properties of the lake water in the system. The temperature during daytime in Malaysia fluctuate between 25 and 33 °C.

Before the treatment, 200 ml of the sample was collected from the tank and stored in clean sampling bottles for water quality analysis. The treated effluent was collected from the system after 3 h of filtration. To ensure the consistency of the result, a measuring cylinder was used to collect 20 ml of lake water from each outlet as an average outflow sample. The

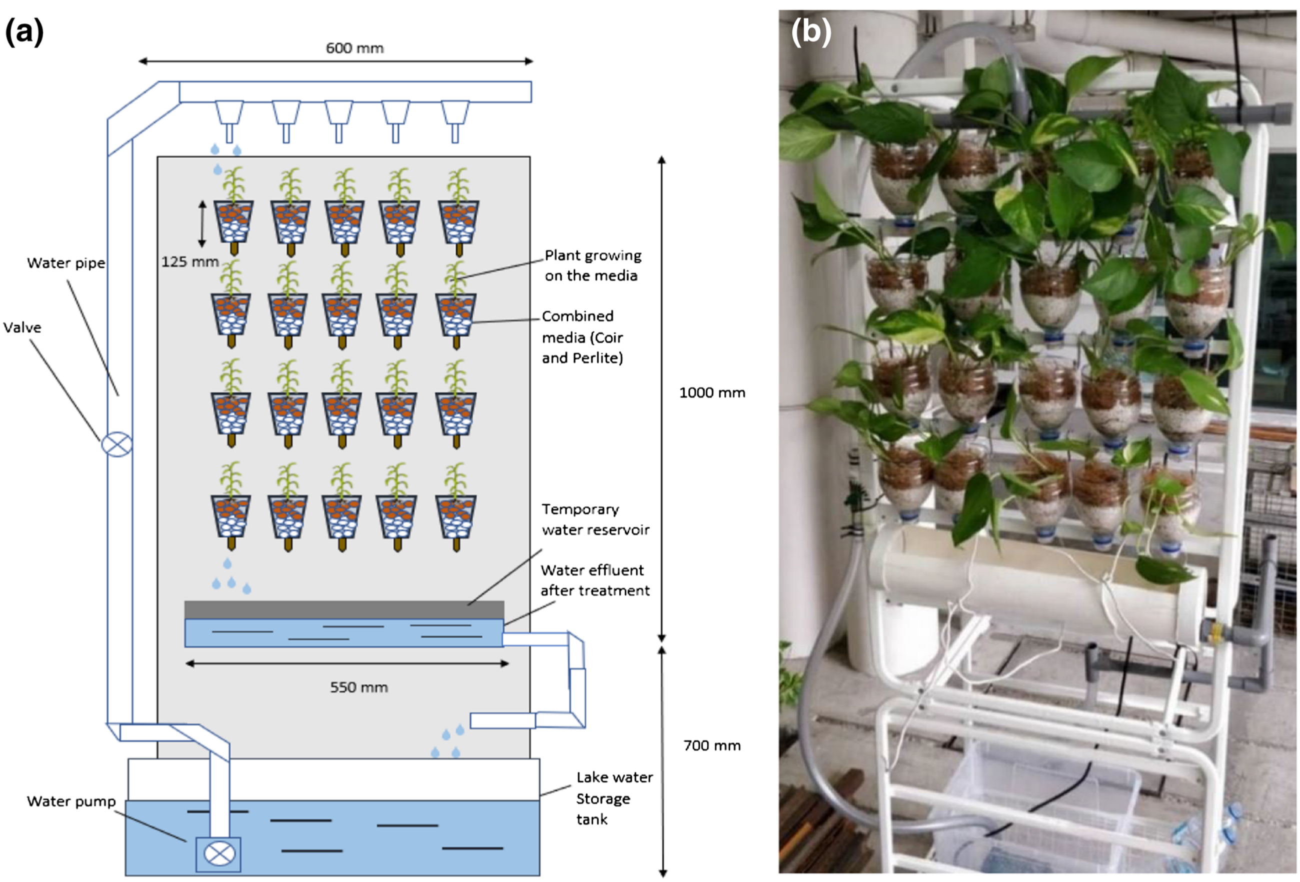

Fig. 1 **a** Schematic diagram of the green wall filtration system. **b** The constructed green wall filtration system

treated lake water samples were then stored in clean sampling bottles throughout the experiment.

Characterization of Lake Water

The lake water used in the study are collected from the lake side in Taylor's University, Selangor, Malaysia. The composition of the lake water samples will be affected by various factors, such as weather, temperature and the surrounding activities. Thus, six parameters were decided to represent the characteristics of the lake water. These parameters include pH, total suspended solid (TSS), chemical oxygen demand (COD), turbidity, total phosphorus content (TP) and total nitrogen content (TN). The characteristics of the lake water were tabulated in Table 1.

Green Wall System Start-up Procedures

Before every treatment cycle, tap water was first pumped into the green wall system to remove any particle or residues that remained in the media. This was also done to compact the filter media and stabilize its structure. The tap water flushing was conducted once a week to ensure the consistency of the lake water flowrate in the system during operation. Throughout the experimental period, the infiltration rate of the system decreased due to the clogging of media. This could potentially be caused by medium contamination, which affects the result of parameters such as TN, TP and COD. Thus, 1 h of system flushing was conducted to reduce the possibility of contamination after any experimental run to ensure the consistency in the flowrate and treatment performance.

Combined Media Ratio

The ratio of the combined media is one of the parameters that can affect treatment performance of the system. In this study, three different ratios of coir and perlite were selected. The selected media height ratio in the container and respective mass of the media are shown in Table 2. The selected ratios were ranged from high-density mix, 3:1 coir to perlite ratio, to low density mix 1:3 coir to perlite ratio.

In order to investigate the effect of combined media ratio on the treatment performance, flow rate at 28 L/h was selected for preliminary trial. The duration for the lake water to recirculate within the system was fixed as 3 h. The fresh lake water samples were treated in the constructed green wall system with each combined media ratio, respectively. The treatment was repeated three times with fresh batch of lake water samples for each ratio. The effluent for treated water and non-treated samples was then analysed. Thereafter, the procedures were repeated with other medium ratios. From the results of water quality analysis, the combined media ratio that provides the highest pollutant removal efficiency was selected as the ratio to carry on with the next study to investigate on the effect of lake water flow rate.

Table 1 Characteristics of lake water

Parameter	Unit	Average	Standard deviation
pH	n. a	8.26	3.56
TSS	mg/L	49.93	26.90
TN	mg/L-N	1.76	1.05
TP	mg/L-P	0.15	0.06
COD	mg/L	571.32	356.36
Turbidity	NTU	37.41	40.51

Table 2 Ratio of the selected combined media

Sample coir (C): perlite (P)	C:P height ratio	Mass of perlite (g)	Mass of coir (g)
A	3:1	24.67	11.42
B	1:1	61.41	8.08
C	1:3	106.00	5.08

Identification of Suitable Flow Rate

In order to identify the suitable lake water flow rate for the constructed green wall filtration system, the effects of different flow rate on the treatment performance were studied. The pollutant removal limit of the combined media with the highest removal performance was tested with various flow rates. In total, three flow rates were chosen for the experiment. The selected flow rate of lake water was shown in Table 3 below.

The lake water flow rate can affect the removal performance and clogging of the combined media. In this study, the valve installed allows the adjustment of lake water flowrate into the green wall system. It was antedate that if the flow rate is too high, the removal performance will be negatively affected as the time is insufficient for biological process to take place [13]. Additionally, it could result in higher operating cost as more energy was required to recirculate the water. Hence, the flow rate beyond flow rate 3 (166.4 L/h) was not considered due to their impracticality.

Table 3 Selected flow rate of lake water

Flow rate	Average flow rate (L/h)	Flow condition
1	10.27	Low
2	28.00	Medium
3	166.40	High

After the treatment, the effluent of each flow rate was analysed through water quality analysis. Hence, the combination of the identified media ratio and flow rate that provides the highest removal efficiency will be recommended as the operating parameters for the green wall system.

Water Quality Analysis

In this study, water quality analysis was conducted to evaluate the treatment performance of the constructed green wall system. The analysis methods were conducted in accordance with the American Public Health Association (APHA) water standard [19]. The water quality analysis was conducted to determine the suitable combined media ratio and flow rate of the green wall filtration system. The samples were analysed for total suspended solid (TSS), pH value, chemical oxygen demand (COD), total nitrogen content (TN), total phosphorus content (TP) and turbidity with specific methodologies. The overall rejection efficiencies of pollutants were calculated using Eq. (1).

$$Rejection\ (\%) = \frac{C_i - C_f}{C_i} \times 100 \quad (1)$$

Where C_i and C_f are the initial and final concentrations of pollutants. The combined media ratio that has the highest rejection efficiency was chosen to further study its hydraulic performance with different flow rates.

Results and Discussion

Treatment Performance of Combined Media of Various Ratios

The treatment performance of the combined media of the selected ratios was evaluated and discussed in the following section. The overall removal efficiency of different combined media ratio of COD, turbidity, TN, TP, TSS and changes in pH were shown in Fig. 2(a)–(f).

The result from Fig. 2(a) shows positive COD removal rate from lake water with the selected ratio of combined media. The combined media ratio 3:1 coir to perlite provides the highest COD removal rate, which is around 53%. In contrast, the removal rate for the ratio 1:1 and 1:3 C:P ratio was substantially lower, which had a removal rate of 27% and 36%, respectively. This outcome suggested that the proportion of coir plays an important role in removing COD. The removal of COD could potentially be caused by biological degradation which is highly dependent on the water retention time in the media [20]. Coir has high specific surface area and wetting ability, which enhanced the adhesion rate of microorganism on the fibre surface [21]. Hence, higher proportion of coir can increase the retention time of water within the media, which enhances the COD removal and leaching of organic particles in the media [13]. However, as shown in Fig. 2(a), the COD removal of ratio 1:1 is lower than ratio 1:3 coir to perlite, which could be due to the accumulation of impurities within the filter media. Hence, the uptake of organic particles in the filtering media was not significant as the impurities on the surface of the filtering media have reduced the effective surface area for COD removal. In addition to that, it could be deduced that the fluctuation of the pollutants in the inlet could result in inconsistent removal. Despite the ability of coir in promoting biological activity on the media, with low inlet pollutant concentration, the COD removal efficiency can be reduced due to the leaching of organic substance entrapped in the media [20]. These organic substances could cause increment in COD, and thus, the removal efficiency was not significant.

On top of that, as shown in Fig. 2(b), turbidity removal percentage from lake water shows a similar trend as COD removal. The overall removal percentage for the three ratios varied from 54 to 24%, then increased to 42% with the decline in proportion of coir in the media. It could be deduced that this phenomenon was not caused by the hydraulic load as the dosing rate of lake water was constant across the three samples of combined media. As such, suspended sediment such as algae and bacteria, could be the factors that contributed to the turbidity of the water. Therefore, the removal could also be governed by the biological characteristics of coir. Therefore, it was found that the highest turbidity removal was associated with the highest coir proportion among the other combination ratios. However, the average inlet concentration for turbidity was 37.41 NTU, which is considered as low inflow concentration. Hence, the leaching of organic particles was likely to happen, which consequently caused results with no consistent removal trend to be observed. The inflow condition for each ratio was the same for water quality analysis. Therefore, the trend of the graph was expected to be similar as other analysis parameters that are dominated by the biological performance of coir. This was further confirmed from the trend observed in Fig. 2(a), where the COD removal for 1:1 ratio is also lower than 1:3 coir to perlite.

Besides, Fig. 2(c) showed that the efficiency of TN removal gradually increased, then decreased along with the decrease in proportion of coir in the media. The result does not comply with the explanation from literature review by [13]. Theoretically, the efficiency of TN removal should be heavily favoured to ratios with higher coir proportion. There were a few factors that could explain this outcome. From the recent study by Veljko (2017), the removal of TN requires significant amount of time for the microbial activity to take place [13]. These removal processes were initiated at the biofilm formed within the media when contacted with water. Hence,

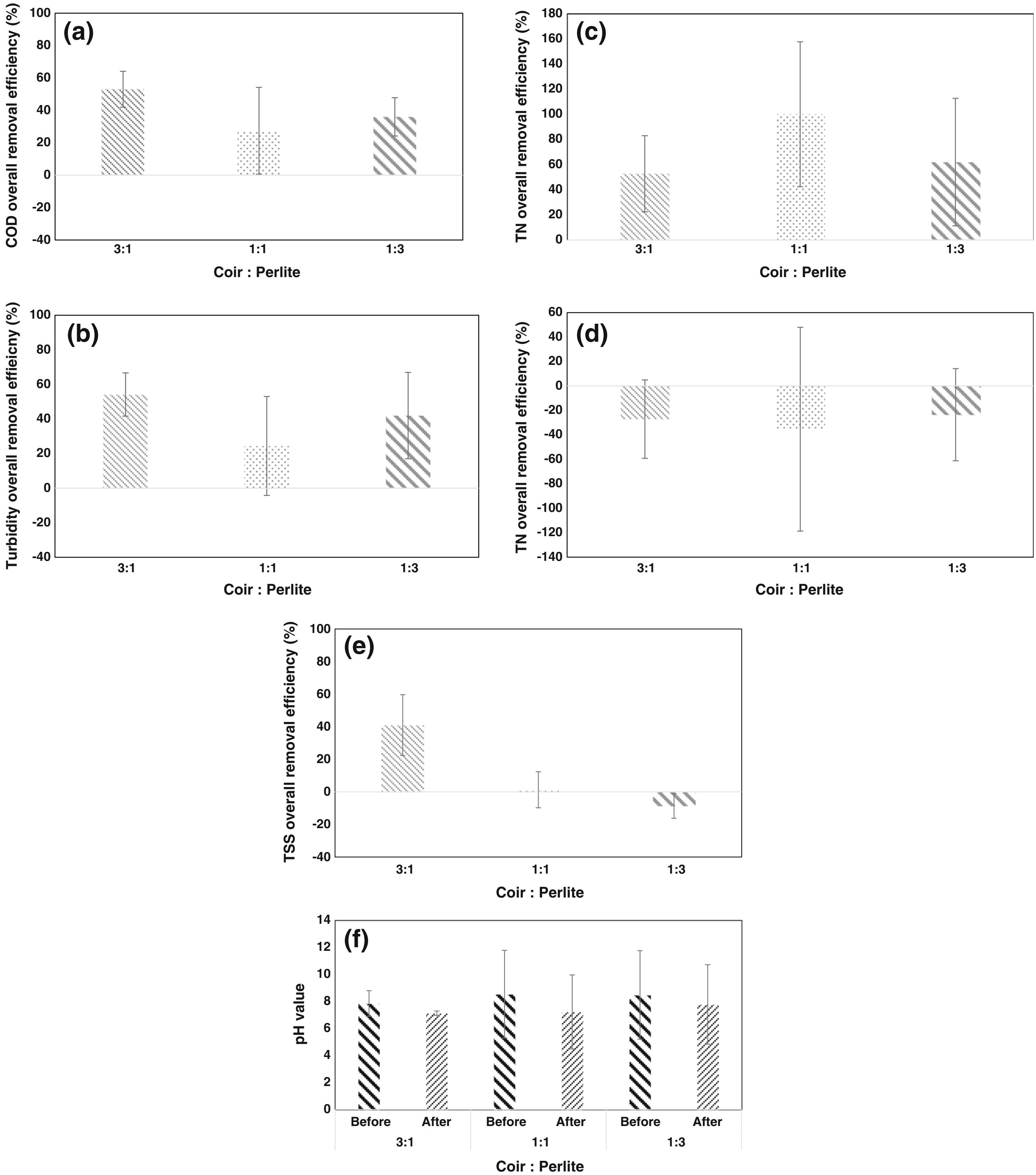

Fig. 2 Overall removal efficiency of **a** COD, **b** turbidity, **c** TN, **d** TP, **e** TSS and **f** changes in pH of selected combined media ratio

longer treatment duration of the system can improve the removal efficiency of TN. Additionally, the constructed green wall system in this study is a recirculating system. Thus, the contact time between water and media is insufficient to initiate the biological process. Another factor can be due to the characteristics of coir. Typically, coir is a material that consists of low nitrogen, calcium and magnesium content but high phosphorus and potassium content [22]. In this experiment stage, the amount of lake water that introduced to the system was the same. Hence, it was possible that the nitrogen content that is stored within the coir was washed out due to the constant circulation of water inside the system, which could be explained by the results of TN removal of 3:1 and 1:3 combined media ratio [20]. The combined media ratio of 1:1 coir to perlite shows dominance in TN removal among the three ratios. The reason could be the low inflow TN concentration of the feed. The inlet TN concentration for 1:1 combined media was slightly lower than the other two ratios, thus small amount of removal can show huge impact in the removal efficiency. Nevertheless, the lake water used in the treatment contains very low TN. Although the removal efficiency of TN fluctuates between 30 and 100%, the exact amount of TN that has been removed was actually insignificant.

Similar to TN, the removal of TP is highly dependent on the biological processes [13]. The phosphorus content is removed as precipitated solid when the phosphate ions in the water react with other metallic ions to form amorphous solids [23]. From Fig. 2(d), the overall TP removal was shown to be limited in the experiment. All the three ratios did not provide a distinctive trend. This phenomenon can be explained by the chemical properties of the filter media. As mentioned, coir is a material that consists of low metal content but high phosphorus content. Hence, the phosphorus removal is difficult due to the limited number of metallic ions present within the combined media [22]. However, leaching of phosphorus content within the media is possible as the lake water was constantly circulating through the system. On the other hand, perlite consists of fair amount of aluminium oxide, iron oxide and magnesium oxide [24]. Hence, this media was supposed to have better phosphorus removal efficient than coir. However, since the media consists of huge pore structure, it reduces the capability to retain the water for biofilm formation. This explained the similar TP removal trend that was observed from 3:1 and 1:3 coir to perlite ratios. Besides, a study has suggested that phosphorus removal and pH are interrelated [25]. It was found that the precipitation of phosphorus is dominated by iron and aluminium in acidic to neutral conditions, whereas it is dominated by calcium in neutral to alkaline conditions [25]. Therefore, the removal of TP from the system could be affected by the pH condition of the influent to the system. The average pH value of the inlet flow was 8.27, which is considered slightly alkaline. Thus, the TP removal performance of perlite was lowered under this condition, which explains the trend of TP increment for all three combined media ratios. Nevertheless, the increment of TP content in treated lake water is insignificant because the inflow TP concentration was minimum. However, the outcome has suggested that coir is not suitable to be used for TP removal when pH is high. Perlite may have better TP removal efficiency but required more studies on its effect in water samples with various pH.

On the other hand, the removal of total suspended solid (TSS) from lake water decreased drastically with the increment in proportion to perlite in the media. In this study, the ratio of 3:1 perlite and coir was found to have the highest TSS removal, which is approximately 41% removal. In contrast, the ratio of combined media 1:1 provides almost no removal in TSS. Moreover, the trend showed increment in TSS in the effluent when higher portion of perlite was used as the media. This phenomenon was related to the properties of two media and the inlet flow rate of lake water. It was suggested that TSS removal was strongly governed by physical pollutant removal processes, such as filtration and sedimentation process [20]. Hence, the TSS content was mainly removed by trapping the solid particles between the pores or adsorbing on the media surface. Although it can be removed through biological process, it was not significant in the case of recirculating system. Nevertheless, coir is a material that has high water holding capacity. Thus, the ratio with high coir proportion showed dominance in TSS removal. Meanwhile, perlite is a material that has lower density compared to water [22]. Therefore, the material tends to float on the water when the flow rate subjected to the green wall is too high. As a result, the solid particles that are trapped within the media were flushed out, which contributed to the increment of TSS concentration. In this experiment, the flow rate used for the treatment was 28 L/h, which is considerably high. Additionally, there were no mesh placed on the top of the media as there were plants growing on each medium container. Thus, the floating of perlite was likely to happen. This explanation complies with the trend from Fig. 2(e), where the higher the proportion of perlite, the lower the TSS removal as more solid particles were flushed out during the treatment process.

As shown in Fig. 2(f), there were no significant pH changes in lake water treatment for the three combined ratios. The pH change was affected by the concentration of hydrogen ions. The higher the concentration of hydrogen ions, the lower the pH value. Therefore, it was suggested that insignificant pH changes were related to the cation exchange capacity (CEC) of the media [22]. CEC is defined as the ability of a growing media to hold positively charged ions. Recent study of growing media has shown that the CEC for both coir and perlite were low [22]. Henceforth, it has high possibility that the hydrogen ion transfer was limited due to this effect, resulting in insignificant change of pH during the treatment process.

Perlite is a pH neutral material. It does not alter the pH or contributes chemical to the water [24]. On the other hand, coir has a neutral pH range of 5.2–6.8. Unlike perlite, coir can change the pH of the incoming water when it undergoes any chemical or biochemical processes [26]. However, the pH changes of lake water in each experimental trial was minimal, suggesting that the plant roots may have contributed in adjusting the pH value through exchanging excess charged ions for charged nutrient ions.

From the analysis above, the 3:1 ratio of coir to perlite has been identified to be the suitable ratio for the green wall filtration system as it provides better overall efficiency in terms of COD, turbidity and TSS. The ratio was utilized to further evaluate its treatment performance across different inflow conditions.

Effect of Various Lake Water Flowrate

The treatment performance of the suitable combined-media ratio with selected lake water flow rate was evaluated. The effect of various lake water flow rate on pH and overall removal efficiency of TSS, turbidity, COD, TN and TP were tabulated in the Fig. 3(a)–(f).

The results have shown that TSS concentration increased to about 62% when using flow rate 3 (166.4 L/h) in the treatment process. It was observed that floating of perlite has occurred in the plant containers, which led to the increase in media bulk porosity. As a result, solid particles such as dust, residue from packaging could be flushed out along with water, which resulted in huge increment of TSS content. This trend does comply with the experimental result from the literature, where the TSS removal efficiency of a media filtration system decreases when the flow rate increases [13]. In contrast, flow rate 1 (10.27 L/h) showed minimal increment in TSS content after the filtration. In fact, particle removal during filtration occurs through the transportation of particular matter from the inflow to the filter media followed by their capture by either adsorption, size exclusion or sedimentation [27]. Thus, it was anticipated that with low flow rate, the water was not distributed evenly when it flows through the media. As a result, clogging is likely to happen as water circulates through the same spot repeatedly. Generally, the removal of TSS and turbidity are correlated. By comparing Fig. 3(a) and (b), the results of flow rate 1 and flow rate 2 show similar removal trend, but it does not apply to flow rate 3. According to the study by Philani et al. (2016), the solid removal efficiency varied inversely with the increment in flow rate, which complies with the result of flow rate 3. However, the negative impact of increased flow rate can be reduced by multiple media layer. As the water flows through each layer, the suspension particle size leaving each of the filter layers decreased progressively [28]. Thus, the suspended particles in the effluent increased but the turbidity value decreased as lesser light was scattered by the small particles.

From Fig. 3(b), a trend in turbidity removal was observed where the efficiency of removal gradually increased from flow rate 2 (28 L/h) to flow rate 3 (166.4 L/h). The turbidity in water is caused by particles suspended or dissolved in water. These particulate matters include clay, fine organic and inorganic matter, algae and microscopic organism [29]. This result has suggested that the removal of turbidity can be affected by the hydraulic loading. It suggested that the capability of the combined media in performing efficient physical adsorption of particulates. As the water circulates through the media repeatedly, more pollutants will be trapped within the media, which resulted in high turbidity removal under appropriate inflow condition. Thus, the trend has suggested that the turbidity removal was affected by the rate of the water circulated in the system. This was further proved by the treatment of flow rate 1(10.27 L/h), which showed poor turbidity removal performance. Under low flow rate condition, the amount of water that flows through the system was insignificant, thus lesser pollutants were filtered by the system. However, the poor turbidity removal could be also caused by the uneven circulation of water within the system. It is possible that only the top water layer was circulated through the system due to low outlet flow. Thus, the turbidity level increased drastically as the pollutants were circulated repeatedly within the system and finally measured at the container outlet.

As shown in Fig. 3(c), the COD removal increased when the lake water flowrate increased from 10.27 to 28 L/h, which varies from 15 to 53%. However, there was almost no COD removed when flow rate was further increased to 166.4 L/h. The COD reduction is mainly driven by both chemical and biological processes [13]. Thus, high flow rate can lead to reduction in retention time of removal, which consequently hindered the biological activity for the removal of COD to occur. In addition, floating of perlite was observed when flow rate 3 was applied. This further increased the infiltration rate as there were more space leading to increase water flow which resulted in the subtle changes of COD content. When the treatment was conducted with low flow rate, the circulation of water within the system was not consistent. As the lake water inflow was low, the lake water outflow would be minimal as well. Thus, it was possible that only the certain layer of water from the water tank was circulated by the system repeatedly. The repeated circulation on the top water layer has caused uneven circulation of pollutants to the media, which reduced the COD removal efficiency in the lake water treatment process.

On the other hand, TN removal was shown to be limited by the changes in flow rates. The result showed no TN removal observed from flow rate 1 (10.27 L/h) and flow rate 3 (166.4 L/h) in the treatment process of green wall, respectively. As the amount of coir used was the same for each of the experimental runs, it proves that hydraulic loading has a significant impact on the treatment. From the result, it was hypothesised that flow rate 3 was too high to be effective in developing a biofilm to initiate microbial processes [20]. Also, the likelihood for the media to flood in the media containers was very high as well. Thus, the infiltration rate was further increased leading to decreased water retention which resulted in the unnoticeable changes of TN content. Although the hydraulic loading of flow rate 1 was considerably low, the data from Table 1 showed that the inflow concentration of TN was very minimal. Hence, it was probable that the TN content carried by the lake water was very low. As a result, there was no TN removal observed from flow rate 1 as the changes

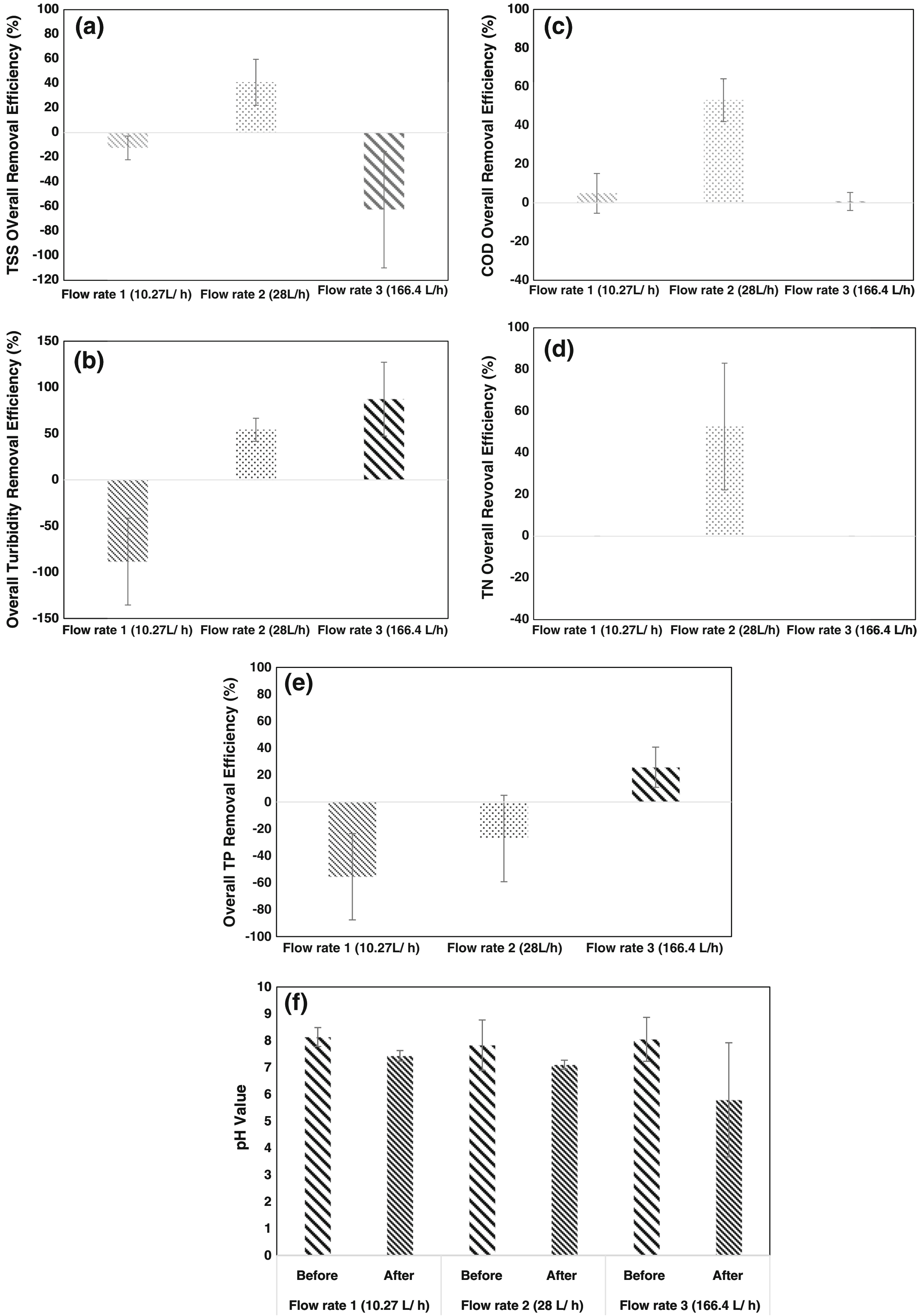

Fig. 3 Overall removal efficiency of **a** TSS, **b** turbidity, **c** COD, **d** TN, **e** TP and **f** changes in pH

were too small to be noticed. Henceforth, there was no clear correlation observed from the results in Fig. 3(d).

From Fig. 3(e), the trend of TP removal was observed where the removal efficiency increased along with the flow rate. The TP removal was shown to be limited from using flow rate 1 (9.27 L/h) and flow rate 2 (28 L/h), respectively. The treatment of flow rate 2 showed lesser increment in TP as compared to flow rate 1. The negative effect of treatment can be explained by the leeching of phosphorus content. Besides, it also could be explained by poor contact between the influent and filter particle [30]. Theoretically, the removal of TP reduces with higher hydraulic load. However, the graph shows a positive removal efficiency of TP when flow rate 3 was applied to the treatment. Thus, it can be debated as to whether the residence time or contact area is the governing factor [30]. During the treatment, the water was released from the top of the constructed green wall system. Hence, larger influent load resulted in splitting the water more evenly on larger surface area of combined media. As a result, it promotes the surface reactions between the combined media and other particles. In contrast, the water distribution with low influent load was not even but has longer residence time. In this case, the contact area could be the governing parameter. According to the study by A.J Erickson, the removal in TP will lead to the increment of TSS value as the phosphorus are removed as precipitation solid [25]. This hypothesis is strengthened by the results shown in Fig. 3(a) and (e), where the trend was observed when flow rate 3 was applied. Hence, it validates the accuracy of the data of flow rate 3 (166.4 L/h). It was deduced that there was an optimum point of flow rate, where the major governing parameter was changed, resulting in the dominance of physical adsorption in TP removal [20].

From Fig. 3(f), the pH value for the three flow rates did not show any significant changes, except for the treatment using flow rate 3 (166.4 L/h). It was suspected that the sudden reduction in pH was caused by the contamination of the media. As mentioned, the removal of pH was related to the CEC of coir and perlite. Hence, it was suggested that the inflow condition does not have any significant impact on the transportation of hydrogen ions between the media and lake water. It is concluded that influent flow rate condition does not have huge impact on pH changes in the lake water treatment process of green wall.

From the analysis above, the outcome shows unsatisfactory removal performance of flow rate 3 (166.4 L/h) in lake water treatment, suspecting that high infiltration rate has resulted in short retention period of water to initiate biological processes. Moreover, it was observed that low influent flow rate can cause uneven circulation of water in the green wall system, considering only the top layer of water was circulated repeatedly within the system. Thus, the pollutant removal efficiency was minimal when flow rate 1 (10.27 L/h) was applied for the treatment. In addition, insignificant pH changes were observed from the treatment results of various lake water inflow conditions, suggesting that pH changes of combined media were not affected by the hydraulic performance. Thus, flow rate 2 (28 L/h) has been chosen as the suitable flow rate for the green wall filtration system as it provides better overall efficiency in terms of COD, TN and TSS. It was found that 3:1 ratio of coir to perlite with influent flow rate of 28 L/h provides the best performance in the conducted experiment.

Practical Implications and Future Perspectives

This work has tested the effect of combined media ratio and flow rate to the treatment performance of green wall filtration system for lake water. It can be served as a preliminary work of testing the capability of green wall in lake water treatment. Thus, the outcome of this research such as operating parameters, treatment conditions and methodologies can be referred as a guideline for future development of green wall in water treatment. However, further considerations on the design structure and green wall elements should be given to further optimize its lake water treatment performance. For example, the survivability, nutrient absorption capacity and the adaptability of the plants to the media should be studied. Other parameters such as wall height, media height and the treatment capacity should also be considered in future green wall systems.

With the current development footsteps of green technologies, the water treatment ability of green wall will certainly be improved overtime. This does not only limit to lake water but also other wastewater source such as kitchen water, black water and greywater. It could be potentially transformed to a sustainable, environmentally friendly and cost-efficient system that is widely applicable to future commercial buildings.

Conclusion

In conclusion, the result of this study has suggested that 3:1 (C:P) combined media ratio with 28 L/h inflow condition provides the highest COD, TSS and turbidity removal from lake water among the other selected flow rates and filter media ratio. In addition, the ratio of combined media and flow rate did not show significant impact in pH changes across the filtration. However, the phosphorus content removal was limited for all the combined media ratios as phosphorus leeching was observed. Besides, treatment conducted with high flow rate (166.4 L/h) and low flow rate (10.27 L/h) showed no significant removal of pollutants in lake water. The outcome of this study can be further optimized by conducting treatment with larger range of combined media ratios and flow rates. Additionally, effect of different types of plants, media pore size, type of filter media and treatment performance on biological parameters could be further studied to optimize application of green wall in lake water treatment.

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Compliance with Ethical Standards

Conflict of Interest The author declares that there is no conflict of interest.

Code Availability Not applicable.

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