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Rainwater treatment with bio-slow sand filtration for sustainable water supply

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ABSTRACT

The water crisis is a problem for almost all countries in the world. Rainwater has the potential to be developed as a water supply due to the large amount of polluted surface water. Bio-slow sand filtration (SSF) has long been proven to be able to improve the physical and biological quality of water. Modification of SSF in this study is bio-activated carbon from *Moringa oleifera* seeds, coconut shells, and lava rock as filter media. This study aims to examine the effectiveness of bio-SSF to treat rainwater as a water supply. Bio SSF uses transparent polypropylene with a diameter of 0.2 m and a total height of 1.5 m. The composition of the media used consisted of lava rock measuring 4.75–12.0 mm (10 cm), coconut shell charcoal measuring 1.18–4.75 mm (10 cm) and *Moringa oleifera* charcoal measuring 0.150–1.18 mm (80 cm). Samples were flown intermittently at a rate of 20 cm/hour at 20–25 °C. Parameters observed were pH, *E. coli*, TDS, Fe, Pb^{2+}, Cd^{2+}, and ammonium. All parameters tested met the requirements for clean water as regulated by the Minister of Health of the Republic of Indonesia No. 32 of 2017.

Keywords: water crisis, rainwater, bio-slow sand filtration, *Moringa oleifera* charcoal, coconut shell charcoal.

INTRODUCTION

Currently, cities and infrastructure are experiencing rapid development along with an increase in population. Fulfillment of social and environmental needs is a challenge in creating a sustainable city in the future. This is what makes water supply a global crisis issue (Ghisi et al., 2009). The global water crisis was first discussed in 1992 at the Earth Summit in Rio de Janeiro where various prevention efforts were outlined in Agenda 21 (Tokarczy-Dorociak et al., 2017). However, these various steps have not been carried out optimally. It can be proven by the data of the availability of freshwater resources consumed by humans are less than 1% (2.5% including frozen and snow-covered) and even then the quality is still questionable due to ongoing pollution from domestic and industrial activities (UNEP, 2008).

Nowadays, all countries in this world are worrying about the shortage of water. The increasingly complex relationship between water use conflicts and the quality of water supply is now becoming a challenge for many countries. Consequently, the practice of rainwater harvesting is becoming an increasingly important instrument for tackling this crisis (Moreira et al., 2017).

Rainwater harvesting technology is not completely new because in recent decades, many countries have already implemented this practice to solve the problems related to the scarcity of water and the increasing demand of water due to the climate, environmental, and social change (Amos et al., 2016). The development of rainwater harvesting has been carried out worldwide to overcome water scarcity (Zhang et al., 2012) due to low water quality for domestic needs (Belmezetti et al., 2014).

The development of rainwater harvesting provides protection for the environment and regional spatial planning because it can form the friendly spaces to accommodate humans and the environment needs (Tokarczyk-Dorociak et al., 2017). Although rainwater harvesting can provide clean water for drinking water as well as for outdoor and indoor uses, it is not widely adopted by local communities in Indonesia (Villar-Navascués et al., 2020).

In urban areas, rainwater harvesting has the potential to be developed because it can supply 80-90% of overall household water consumption (Ghaffarian Hoseini et al., 2015) apart from being a water conservation effort (Zhu et al., 2004). Several parameters to watch out for in rainwater include the value of electric conductivity and total suspended above the threshold. In addition, the presence of dust particles, leaves, and animals also needs to be concerned for. Total coliforms (TC), fecal coliforms (FC) and *Escherichia coli (E. coli*) levels have also been affected by the using of containers that are opened, prolonged storage in dirty containers, and the bad maintenance of containers (Pineda et al., 2021). WHO encourages that coliforms contained in water used for domestic purposes are not more than 10 CFU/100 ml in 95% of the tested samples (Zdeb et al., 2020).

Slow sand filtration (SSF) is effective for water purification especially in removing dissolved particles and microorganisms in the water. In addition, SSF is able to remove several toxic and harmful chemicals from water (Hasan et al, 2022). In general, flow rates are used in the range of 100–200 l/hour/m^2 to remove 98–99% of bacteria. However, if operated at a slower rate or with some pre-treatment, the bacteria removal efficiency can reach 99.5–99.9% (Lakshminarayana et al., 2017). Some rural areas in China, such as Hubei, Fujian, Sichuan, and Guangxi, have tried to implement the technology to purify water by using the SSF. This system is considered cheap, easy to operate, and does not require expensive operational costs in maintenance (Liu et al., 2019).

The SSF is constructed with an initial layer of sand and supernatant water which each size is 1 m. While sand grains can be from 0.15 mm to 0.35 mm, the uniformity coefficient should be less than 5 and it can be much better if it is below 3. Filtration rates is approximately from 0.1 m/h to 0.3 m/h (Fitriani et al., 2022). The materials needed for the substrate as well as the entire construction are widely available at low prices. There are no specific provisions regarding the type of filter media used to allow the utilization of local material resources. Conventional SSF development continues to be carried out to improve its performance. Due to the development of conventional SSF, the bio SSF method can effectively work in removing bacteria and other microbiological contaminants as well as nitrogen, turbidity, heavy metals, ammonia, and organic matters (Liu et al, 2019). This study is conducted to determine the effectiveness of slow sand filtration to treat rainwater as an alternative water supply.

MATERIAL AND METHODS

Construction of bio-slow sand filter

The slow sand filtration system consists of 3 sections, namely: a) an intake tank to collect the rainwater, b) a peristaltic pump to flow the rainwater from intake tank to the filtration, and c) a bio-slow sand filtration reactor to purify the rainwater (Liu et al., 2019). This process can be seen in Figure 1. The construction of bio-SSF can be made of several materials including polyvinyl chloride (PVC) pipes, perspex tubes, transparent polypropylene, or glass fiber (Verma et al., 2017). This study used transparent polypropylene material with an inner diameter of 0.2 m in the reactor and a total height of 1.5 m. To prevent the algae growth that can affect the process, the top of bio-SSF is covered with aluminum foil. The composition of the filter media from below consists of lava rock in the underdrain section as deep as 10 cm (size 4.75–12.0 mm), followed by a 10 cm separating layer in the form of coconut shell charcoal (size 1.18–4.75 mm) and at the top is *Moringa oleifera* charcoal as deep as 80 cm (0.150–1.18 mm in size). The thickness of each medium refers to previous studies (Verma et al., 2017) (Ahammed and Davra, 2011).

Media preparation

The filter media used are generally sand and gravel, but other locally available media can be used (Verma et al., 2017). One of the filter media that is often used because it is available locally is wood charcoal. However, this material is slowly being abandoned along with the increasing rate of deforestation globally (Cobb et al., 2012). One of materials that can be used as a carbon source is coconut shell charcoal. Coconut shell charcoal has the potential to be developed as a carbon source because it comes from coconut shell waste

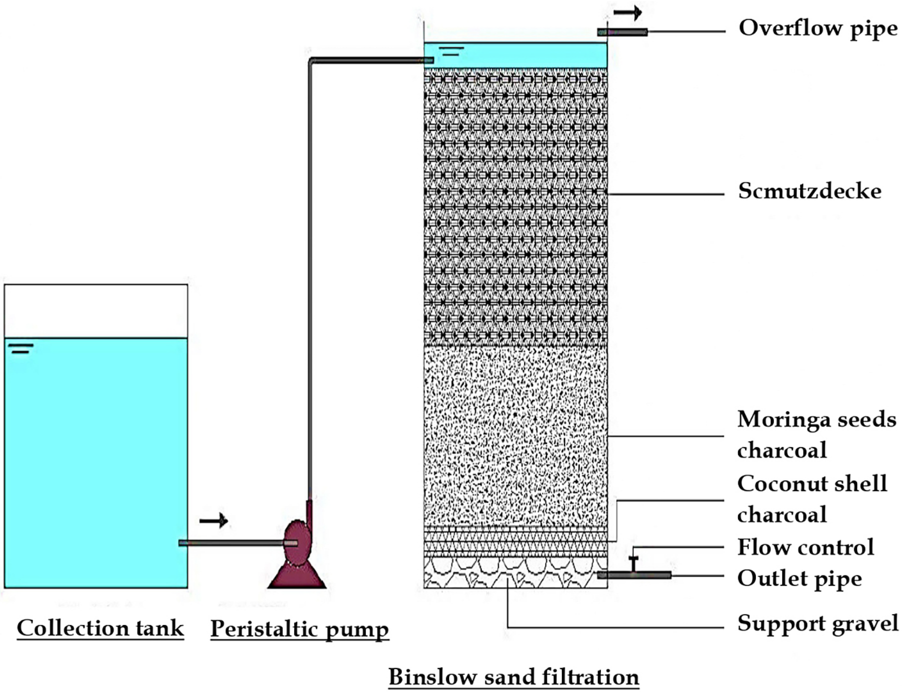

Figure 1. Schematic diagram of bio-slow sand filtration

that is no longer utilized. Utilization of this waste is one of the efforts to save the environment.

An iron tank or drum with the capacity of 200 L is used to burn coconut shells. This process will produce activated charcoals. On the bottom of drum used is punched with 4 dots measuring 1⁄2”. At the top, a 3” hole is created and then connected to a 3” steel pipe until it touches the bottom of the inner drum of 920 mm long. Each end of the iron pipe is welded at the bottom and top. At the top end can be opened and closed. Initially, coconut shells are added little by little and burned until it produces a bluish flame. Furthermore, the top pipe is closed tightly and left overnight until the coconut shell turns into charcoal. The chilled charcoal is removed from the combustion drum to be crushed with size of 1.18–4.75 mm. The activation process was done by soaking coconut shell charcoal for twenty-four hours using the solution of twenty-five percent of $CaCl_2$. Furthermore, the charcoal is rinsed thoroughly and left to dry in the sun (Cobb et al., 2012) (Khayan et al., 2019) (Khaerudin and Rahmatullah, 2021).

The next filter media is activated carbon produced from *Moringa oleifera* seeds. The reason of choosing this material is the efficacy of *Moringa oleifera* for purifying water and being an anti-bacterial (Xiong et al., 2017) (Varkey, 2020) (Delelegn et al., 2018). However, the use of *Moringa oleifera* seeds as activated carbon has not been widely implemented. The process of making *Moringa oleifera* charcoal begins with manual peeling of the seeds. Before being dried in an oven at 110 °C for twelve hours, it should be washed first. The dried seeds from the oven are then crushed to a standard size of 0.15–1.18 mm. The biomass was then pyrolyzed for 60 minutes at 800 °C with a nitrogen flow of 5 mL min-1 using a stainless-steel reactor with a constant heating rate of 30 °C min^{-1}. Heating at 800 °C was chosen because it gives better performance than heating at 600 °C (Khorsand et al, 2017). The activation process was carried out after the pyrolysis process using NaOH. The carbon obtained was soaked in 1 M NaOH solution for two hours, magnetically stirred and dried at 105 °C for four hours. After the carbon had cooled, it was washed with a 0.1 M HCl solution and hot distilled water to a pH of about 7.0. This process is performed to remove residues of activators and other non-organic materials produced during the process. In the washing step, a membrane filter is used for separating activated carbon. The carbon obtained was dried at 105 °C until completely dry and stored in sealed bottles for further analysis (Santos et al., 2020).

At the bottom of the filter media, lava rock is used due to two main reasons. First, the availability of lava rock is in large quantities. Second, lava rock has specific surface area of about eightfold than that of quartz and gravel (Katukiza et al., 2014). Lava rock used as filter media has been washed until it became clean and dried in the sun.

Rainwater sample

Samples were taken from harvested rainwater and stored in plastic reservoirs. The water is then poured into the sample bottle. During the shipping process, the samples were sealed, labeled, and stored in boxes using ice (Khayan et al., 2019). Samples were analyzed before being put into the SSF reactor to determine the initial characteristics. The characteristics of the rainwater that became the sample of this study are listed in Table 1.

The physical-chemical characteristics of rainwater used in this study tended to be acidic with a pH value of 5.8. The pH value tends to vary depending on the amount of CO_2 dissolved in the raindrops. Evaporations on the characteristics of rainfall in certain season and the increase in the number of particles in the atmosphere can be the reason of this condition. The variability in the range of values can be attributed to local influences, electrical conductivity (EC) and total dissolved solids (TDS) measured in different seasons. Indeed, EC is directly proportional to TDS, which is strongly dependent on the concentration of dissolved ions, the ionic strength, and the temperature of the water. Likewise, rainwater turbidity measured in all seasonal samples showed lower values indicating a lower presence of suspended particles in the atmosphere (Valappil et al., 2020).

Experimental set up

In the initial stage, rainwater flowed into the SSF reactor for fourteen days to make sure that microorganisms grew on the filter media (Campos et al., 2002). Microorganisms grew under an acclimatization process until they reach a stable condition. Observations of the growth of schmutzdecke, a brownish slimly layer, were conducted every day (Fitriani et al., 2022). The variations of schmutzdecke layer thickness were from 0.5 to 2.0 cm (Tyagi et al., 2009). In the next stage, rainwater samples flowed into the reactor at a speed of 20 cm/hour. The ambient temperature was 20–25 °C (Liu et al., 2019). The jetting process was carried out intermittently with the consideration of effectivity and reliable removal of organic matter and complete ammonium nitrification. In addition, this method was chosen because it creates a stationary condition in the filter thereby giving bacteria the opportunity to increase their growth resulting in a higher reduction of bacteria and viruses (Elliott et al., 2008).

When the filter was running, water flew downward through the filter bed entering the highly active schmutzdecke layer to remove the pollutants (Yusuf et al., 2019; Fitriani et al., 2022). Rainwater samples flowing from the effluent were taken and analyzed every 10 days for 80 days. Water quality analysis was carried out to determine the performance evaluation of the filter on several physical, chemical, and bacteriological properties of water before and after filtering pH, *E. coli*, TDS, Ammonia Nitrogen, trace elements (Fe, Pb^{2+}, Cd^{2+}) referring to "Standard Methods for the Examination of Water and Wastewater" (Standard Method, 1937). Analysis was carried out on lava rock, coconut shell charcoal, and *Moringa oleifera* seed charcoal.

RESULTS AND DISCUSSION

Effect on pH

pH is the level of acidity or alkalinity of a solution that indicates the quality of water. In general, the pH value is in the range of 6.5–8.5 but can vary depending on the material composition (Castro-Jiménez et al., 2022). The rainwater

Table 1. Characteristics of rainwater samples

Parameter	Unit	Measurementresults	Regulation of the Minister of Health of the Republic of Indonesia No. 32/2017
pH		5.8	6.5–8.5
E. coli	CFU/1 00 mL	55	50
TDS	mg/L	86	1000
Fe	mg/L	1.56	1
Pb^{2+}	mg/L	0.38	0.05
Cd^{2+}	mg/L	0.3	0.005
Ammonia	mg/L	1.4	-

samples had an initial pH of 5.7 ± 0.02, but then there was an increase in pH to 6.8 ± 0.01 – 7.5 ± 0.02 in the effluent as shown in Figure 2. A significant increase in pH from 6.75 ± 0.01 to 7.22 ± 0.04 also occurred in the treatment of wastewater containing fungicides using the biological filtration method with a combination of sand and activated carbon media (Azis et al., 2021).

The increase of pH in this study was due to the exchange of rainwater anions on the surface of the *Moringa oleifera* seed charcoal. In this process, the basic amino acids contained in the charcoal protein of Moringa seeds accept protons in water resulting in the release of hydroxyl groups which causes the solution to become alkaline (Azis et al., 2021; Moravec et al., 2008; Hendrawati et al., 2016). The processed rainwater has a pH range of 6–8 as recommended by WHO (Hendrawati et al., 2016). The pH value that increases towards neutral causes the adsorption capacity of the *Moringa oleifera* seed charcoal to decrease (Geleta et al., 2021).

Effect on *E. coli bacteria*

Utilization of rainwater is one of the efforts to find alternative water sources other than surface water. One of the problems with surface water is the presence of coliform bacteria as a trigger for waterborne disease. Coliform bacteria are facultative anaerobic microorganisms that can grow in aerobic environments or low pH but cannot grow in environments with alkaline pH (Hendrawati et al., 2016). *Moringa oleifera* seed extract has great potential as a disinfectant (Idris et al., 2017). The protein in *Moringa oleifera* which is ground and

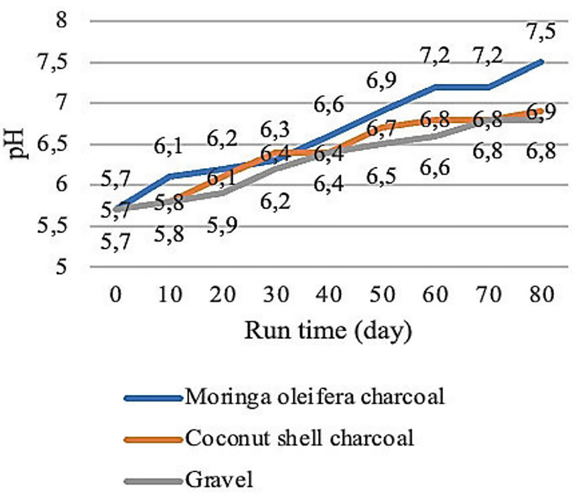

Figure 2. Effect on pH in bio SSF

dissolved in water will produce a positive charge that acts like a magnet by absorbing negatively charged particles such as toxic particles (Hendrawati et al., 2016). In this study, the use of *Moringa oleifera* seed charcoal has an impact on increasing pH which ultimately stops the growth of *E. coli* bacteria. The efficacy of *Moringa oleifera* has also been proven in research conducted by Mumuni et al, where the use of *Moringa oleifera* seed powder in a multi-stage sand filter to treat domestic wastewater was able to significantly reduce *E. coli* bacteria by around 99.94% and *E. coli* by 99.97% (Udayasri et al., 2012).

The advantage of using activated carbon is that it has high porosity and absorption capacity for various pollutants (Azis et al., 2021). SSF is a simple treatment technology that is effective in removing pathogens from water. SSF is effective in removing polluting organisms from rainwater to be used as drinking water (Seeger et al., 2016). The results show that SSF with a combination of moringa seed charcoal-coconut shell charcoal-gravel media can remove *E. coli* bacteria up to 100%. The bacteria removal process occurs at the top of the *Moringa oleifera* seed charcoal layer. The decrease in the number of bacteria occurs through several mechanisms, namely: 1) sedimentation in the upper waters, hydrolysis and photosynthesis of organic matter, 2) degradation, filtration, and blocking of contaminants by the microecological environment in the schmutzdecke layer; and 3) increased decomposition, blocking, and filtration of pollutants to depth. In general, SSF pollutant filtration includes two components, namely adsorption and biochemical mechanisms (Liu et al., 2019). The biochemical process in SSF is followed by adsorption, mechanical filtration, and degradation (Adin, 2003).

The use of slow filtration rates and media is a crucial factor in contaminant removal (Elliott et al., 2011). A filtration rate of 0.2 m^3/hour (range 0.1–0.3 m^3/hour) was used in this study so that the removal mechanism was optimal, however, the removal capacity tended to decrease with increasing run time as shown in Figure 3. In this study, the initial *E.coli* content was 55 CFU/100 mL then decreased to 0 CFU/100 mL as shown in Figure 3. The highest bacterial removal efficiency was obtained at the finer grain size (Yogafanny et al., 2014). This is consistent with the findings in this study where the removal of *E. coli* in the *Moringa oleifera* seed charcoal layer was 14.54–66.67%, while the coconut shell charcoal and lava

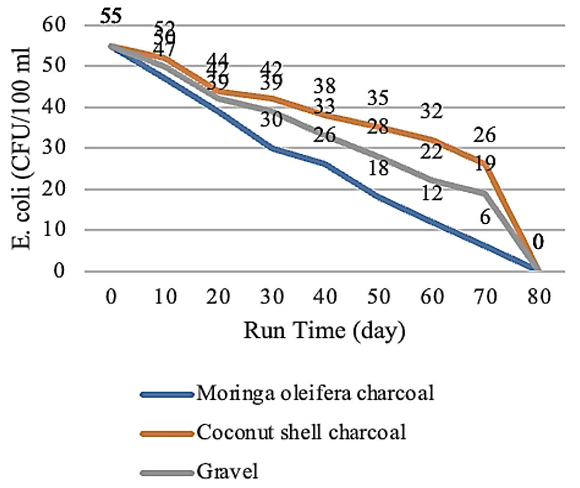

Figure 3. E. *coli* removal in bio SSF

rock layers each obtained removal efficiencies of 5.45–18.75% and 9.09–13.63%.

Effect on TDS

One of the most important parameters for evaluating SSF performance is turbidity. Higher turbidity removal efficiency was obtained from research conducted by (Tyagi et al., 2009) compared to Al-Adham due to the higher depth of the filter with sand media. This means that the adsorption capacity decreases as the depth of the media layer decreases. However, there are other determining factors besides the media layer in the form of characteristics and types of wastewater (Verma et al., 2017). Turbidity removal in SSF is usually in the range of 59–90% (Ahammed and Davra, 2011; Yogafanny et al., 2014). There are several methods to increase turbidity removal including the level of filter media roughness (Nkwonta, 2011), ozonation with a certain pressure (Cha et al., 2010), and metal coating on sand media (Hsu et al., 2008). In addition, the filter operating mode also has an effect, where continuous operation is more effective than intermittent mode (Young-Rojanschi and Madramootoo, 2014).

In this study, a modification of the filter media using *Moringa oleifera* seed charcoal and coconut shell charcoal was chosen to increase the efficiency of turbidity removal. This is based on the consideration that the focus of the treatment is on reducing *E. coli* compared to low turbidity in rainwater. Therefore, an intermittent filter operation mode is used for the reduction of *E. coli* bacteria is higher even though it is known that the continuous operation mode gives the best results.

The TDS value detected in rainwater samples was 86 mg/L which then decreased gradually over time during the filtration process. The highest percentage of TDS removal was obtained in the *Moringa oleifera* seed charcoal layer with an efficiency of 16.66–50% as shown in Figure 4. Furthermore, the percentage of removal increased in the coconut shell charcoal layer by 9.09–41.26% and the smallest percentage of removal occurred in the lava rock layer by 5.76–30.55%. The TDS value decreased gradually with increasing depth of the filter media where most of the contaminants were blocked by the schmutzdecke on the surface layer. Contaminants that escaped the schmutzdecke penetrates to the bottom with the water flow (Liu et al., 2019).

In TDS removal, the use of *Moringa oleifera* seed charcoal of 750 mg/L and 1500 mg/L was able to reduce TDS from 3.180 mg/L to 690 mg/L (reduction efficiency of 78.3%) and from 3.180 mg/L to 164 mg/L (reduction efficiency of 94.84%). However, the high removal efficiency is still not able to meet the wastewater quality standards in the regulation of the Ministry of Environment of Indonesia No. 5 of 2014 (should be 50 mg/L).

Effect on trace metal

Metals are widely known to cause several serious diseases (Srivastava and Majumder, 2008). SSF with sand media is significantly able to remove high concentrations of arsenic, iron, and manganese from groundwater (Johannsen et al., 2016). Several previous studies, including the results of Mbir and Tetteh-Narh's research, stated that sand filters were able to achieve an average Fe removal efficiency ranging from 37.7 to

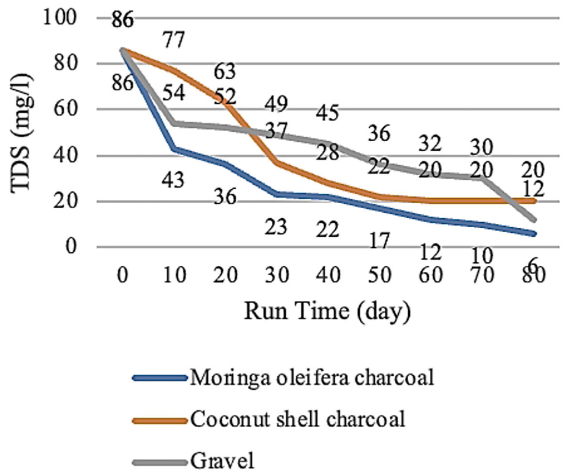

Figure 4. TDS removal on bio SSF

84.1% (Fujita et al., 2022). In addition, Khatri et al. reported an Fe removal efficiency of 90.15% at a sand layer thickness of 0.60 m (Khatri and Rawtani, 2017). Both of these results are relatively low compared to those reported by Zhang et al who obtained an Fe removal efficiency of 97.9–99.9% and the Pb metal removal efficiency increased from 31–61% to 61.2–98.8%. (Zhang et al., 2012). Other results mention the achievement of Fe removal efficiency Pb up to 100% when using activated charcoal media. Furthermore, the average Cu removal efficiency was reported to increase from 32.8% to 66.2–85.3% (Fujita et al., 2022). The Fe content in rainwater samples was detected at 1.56 mg/L which then decreased to 0.1–0.3 mg/L through SSF biotreatment as shown in Figure 5. The Fe removal efficiency in the *Moringa oleifera* seed charcoal layer was obtained at 23.7–66.7%, then decreased by 13.46–50% in the coconut shell charcoal layer and by 16.66–50% in the lava rock layer. These results are in line with previous studies where in general the Fe removal efficiency with SSF is not too high, which is around 50–60% because Fe is best removed from water through the oxidation of Fe^{2+} to Fe^{3+} (King-Nyamador et al., 2020).

In the removal of Pb^{2+}, the removal efficiency was obtained at 15.79–71.42% for the *Moringa oleifera* seed charcoal layer with an initial content of 0.38 mg/L, then for the coconut shell charcoal - lava rock layer, the results were obtained at 6.67.9–50% and 7.89% - 50%, respectively. The Pb^{2+} effluent produced was 0.01–0.02 mg/L as shown in Figure 6. While the removal of Cd^{2+} detected at 0.3 mg/L in the sample, the removal efficiency was obtained at 20–50% in the *Moringa oleifera* seed charcoal layer. Not much different results were produced by the coconut shell charcoal - lava rock layer with removal efficiencies of 25–50% and 16.67–50%. The Cd^{2+} value in the effluent was 0.003–0.005 mg/L as shown in Figure 7. Removal of heavy metals occurs due to metal adsorption into the schmutzdecke and adhesion to the filter media granules (Zaid et al., 2019). In this study, the porosity and large surface area of the *Moringa oleifera* seed charcoal media - coconut shell charcoal - lava rock were able to adsorb and neutralize Fe, Cd^{2+} and Pb^{2+} charges.

Effect on ammonium

Ammonium can be found naturally in water bodies or from microbiological decomposition of nitrogen compounds in organic matter, waste from fish and aquatic organisms, domestic wastewater, fertilizers and animal waste (Zaid et al., 2019). These various sources of ammonium then undergo a process of condensation of water vapor in the atmosphere into water droplets which then fall into rainwater. Ammonium has a major effect on the acidity of rainwater and ecosystems (Keresztesi et al., 2018).

In SSF treatment, where the filtration rate is 20 cm/hour, the nitrification and denitrification processes occur simultaneously and higher dissolved oxygen (DO) is transferred to the media. The use of a filtration rate of 20 cm/hour is motivated by the decrease in NH_4^+-N removal at a filtration rate greater than 0.6 m^3/hour. Higher filtration rates, in the range of 10–20 cm/hour, promote the nitrification process that converts ammonium to nitrate

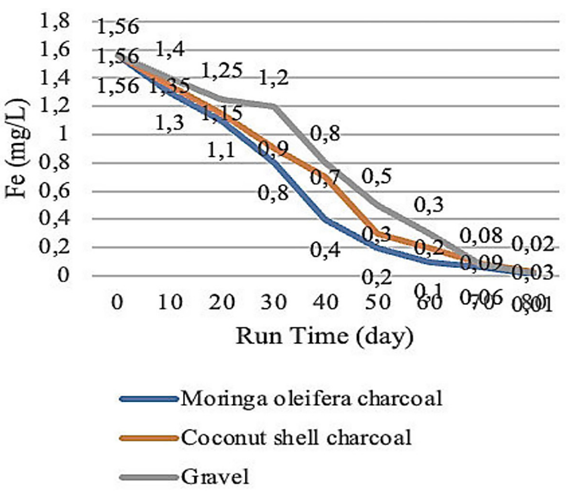

Figure 5. Fe removal in bio SSF

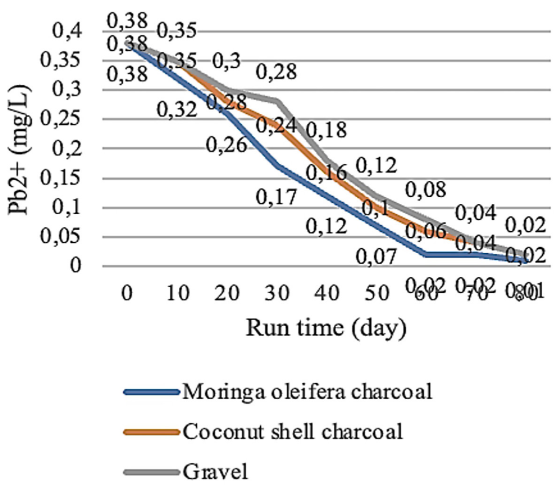

Figure 6. Pb^{2+} removal in bio SSF

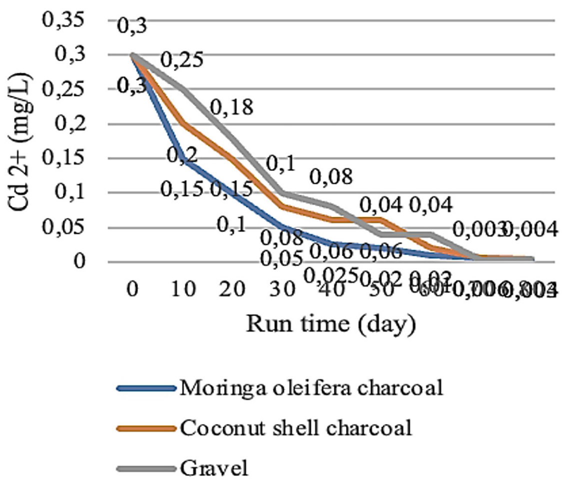

Figure 7. Cd^{2+} removal in bio SSF

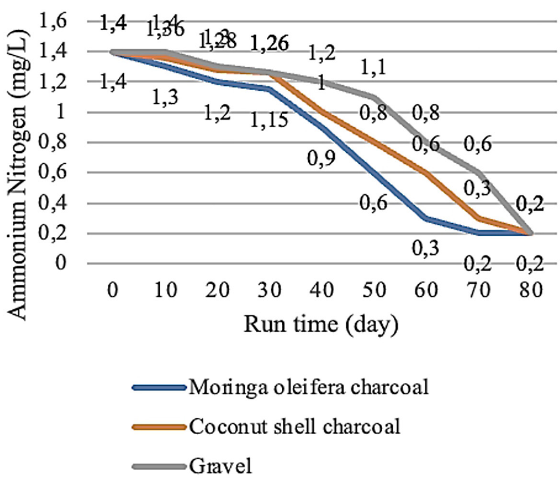

Figure 8. Ammonium removal in bio SSF

and denitrification where nitrate becomes nitrite and then nitrogen (Li et al., 2018). In this study, the ammonium content was detected at 1.4 mg/L which then decreased to 0.2 mg/L in the effluent.

In this study, the elimination of NH_4^+-N was caused by the absorption of the filter media, especially coconut shell charcoal and lava rock. However, the percentage of ammonium removal was not high enough in the bio SSF. This can be seen in Figure 8, where the *Moringa oleifera* seed charcoal layer obtained an efficiency of 7.1–50%. Furthermore, the coconut shell charcoal layer obtained an efficiency of 2.8–50% and 3–66.67%.

The low percentage of ammonium removal by *Moringa oleifera* seed charcoal is due to the positive charge of *Moringa oleifera* seed charcoal which is unable to attract the positive charge of ammonium (Zaid et al., 2019). The elimination efficiency is relatively unchanged in the coconut shell charcoal layer. However, in lava rock, the efficiency increases again to 66.67% in lava rock media. The increase in elimination capacity is due to the higher specific surface area. Simultaneous nitrification-denitrification has been shown to depend on sand size, filtration rate, and media depth (Verma et al., 2017).

CONCLUSIONS

Bio SSF with the composition of *Moringa oleifera* seed charcoal – coconut shell charcoal – lava rock media has proven effective for rainwater treatment as an alternative water source as mandated in the Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017. The characteristics of the results of bio SSF treatment for rainwater treatment are as follows:

a) There was an increase in pH from pH 5.7 ± 0.02 to 6.8 ± 0.01 – 7.5 ± 0.02. The percentage of removal of *E.coli* was 14.54–66.67% respectively in the *Moringa oleifera* seed charcoal layer, while in the coconut shell charcoal and lava rock layers each obtained removal efficiencies of 5.45–18.75% and 9.09–13.63%.
b) The highest percentage of TDS removal was obtained in the *Moringa oleifera* charcoal layer with an efficiency of 16.66–50%. Furthermore, the percentage of removal increased in the coconut shell charcoal layer by 9.09–41.26% and the smallest percentage of removal occurred in the lava rock layer by 5.76–30.55%.
c) In the elimination of trace metals (Fe, Pb^{2+} and Cd^{2+}) the results for Fe were 23.7–66.7% in *Moringa oleifera* seed charcoal. While the results of Fe removal in the coconut shell charcoal – lava rock layer obtained results 3.46–50%, and 16.66–50%. Provision of Pb^{2+} obtained a removal efficiency of 15.79–71.42% in the *Moringa oleifera* seed charcoal layer, then in the coconut shell charcoal – lava rock layer the yields were respectively 6.67.9–50% and 7.89–50%. Whereas in Cd^{2+} removal, a removal efficiency of 20–50% was obtained for the *Moringa oleifera* seed charcoal layer, 25–50% for the coconut shell charcoal layer and lava rock and 16.67–50%.
d) The removal of ammonium was 1.4 mg/L which then decreased to 0.2 mg/L in the effluent. The percentage of ammonium removal is not too high in bio SSF, where the *Moringa oleifera* seed charcoal layer obtains an efficiency

of 7.1–50%. Furthermore, in the coconut shell charcoal layer, the efficiency of 2.8–50% and 3–66.67% was obtained.

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