The Investigation on Mineral Wool Performance as a Potential Filter to Remove TSS in Cikapayang River, East Jawa, Indonesia

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ABSTRACT

Mineral wool has been used as a filter medium that reaches approximately 95% removal efficiency of total suspended solids (TSS) on a laboratory scale. However, there is no research available has been applied on a larger scale. Hence, this study investigated the ability of mineral wool to remove TSS in two separate segments of the Cikapayang River at different seasons. This analysis utilizes a mineral wool type I, with a dimension of 180×30×120 cm placed in segment 2, and a mineral wool type II with a dimension of 325×30×100 cm placed in segment 9. Samples were taken using the grab sampling method to analyze the TSS concentration before and after being filtered by mineral wool. This investigation concluded that mineral wool could reduce the TSS concentration by up to 65%, and the removal capacity increased by about 6.82% during the dry season. The concentration of TSS in the dry season positively correlates with the increase in the removal capacity of the media. Mineral wool of type I in segment 2 had a better removal ability (31.43%) than type II in segment 9 (14.71%). This research shows that mineral wool can be used as a support material in sanitation sites in large cities experiencing quality degradation in their water bodies.

1. INTRODUCTION

Surrounded by the most developed area with the most populous in Indonesia (Pynkyawati et al., 2020), Bandung, Cikapayang River is used to dispose of domestic wastewater. The current condition shows that the amount of pollutants contaminating has exceeded the carrying capacity and cannot be assimilated naturally, especially the TSS as a dominant pollutant, according to Prayogo et al. (2020) and Yacub et al. (2022). The water becomes turbid and filled with mud, especially during the dry season. Domestic wastewater contains TSS with concentrations varying from 77-382 mg/L (Widyarani et al., 2022) depending on the population and its activities. TSS is the concentration of suspended and insoluble material in the river that can be trapped by filter media (Gong et al., 2016; Butler and Ford, 2018). TSS includes various types of material, such as decomposed mud, plants, and animals (Gong et al., 2016). The transfer of TSS in the water flow is a crucial part of the material cycle, especially for carbon and nitrogen (Doxaran et al., 2009). Therefore, the increasing TSS concentration leads to increased pollution. This topic has received significant attention worldwide, such as Citarum River (Marselina et al., 2022), Elemi River (Folorunso, 2018), Nomi River (Miura et al., 2019), Pará River (Carneiro et al., 2020), Hau River (Nguyen et al., 2020), and Nakdong River (Kwon et al., 2021). Many experiments had been carried out in the laboratory simulating TSS removal in water streams. However, it could not be compared to field-scale.

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Mineral wool is a 100% natural and environmentally friendly media derived from volcanic lava that can filter TSS on a laboratory scale (Hao et al., 2019). It has a high adsorption capacity, material surface contact, low density, is easy to set in the river, and the water saturation content was twice as high as other granular media. Aphirta et al. (2020) tested 27 cm^3 mineral wool to determine the capacity of TSS removal on a laboratory scale using the Plug Flow Reactor (PFR) system to simulate the Cikapayang River condition with a volume of 10.78 L. The study resulted in the highest removal of 95%. Based on various existing problems and previous mineral wool studies, they were able to eliminate TSS. So, this study aimed to investigate the ability of mineral wool to remove TSS in a field scale in the Cikapayang River, which is influenced by seasons.

2. METHODOLOGY

2.1 Materials

This study used two types of mineral wool from Drainblock B.V. Netherlands as a filter media (Table 1). These two types have been claimed to increase water quality (Merola, 2018; Aphirta et al., 2020; van Jaarsveld, 2020). They were tested to determine the success rate of each product with different Indonesian surface water conditions compared to the Netherlands and to find the best product that can be applied from both. Mineral wool type I was placed in segment 2, while type II is placed in segment 9 as shown in Figure 1. In its application, the length and depth of the mineral wool was adjusted for each segment and is inserted into a supporting frame made of steel.

Table 1. Two types of the characteristic of mineral wool used in this study

Mineral wool	Type I	Type II
Picture		
Density	80 kg/m^3	120 kg/m^3
Water retention capacity	95%	92%
Hydraulic conductivity	6 mm/s	7 mm/s

2.2 Study area and time

The study was located in Cikapayang River, West Java, Indonesia. It is in a tropical area and has an average annual atmospheric temperature of 22.63°C and rainfall of 189.02 mm (Jaya et al., 2020). As a result of restoration, the Cikapayang River at City Hall Bandung has 12 segments with different lengths, widths, and depths. Each segment is limited by a plunge with a height varying from 15-100 cm. Due to field-scale experiments, segment selection in this study is influenced by many factors such as approval by the government, security considerations, and ease of installation. This collection point serves around 35,000 people and includes some small industrial wastewater. The study was conducted in January-March 2019 (rainy season period), followed by April-August 2019 (dry season period). One period of sampling was conducted consecutively for seven days. River water samples were taken before and after through each mineral wool type using the grab sampling method at 9:00 a.m. to represent the peak of domestic activity.

2.3 Data collection

Water samples were taken manually from the middle at a depth of 50 cm below the water surface using a plastic scoop with a handle (Suriadikusumah et al., 2021). River discharge was measured by determining the water velocity (m^2/s) and multiplying it with the height of the water surface (m). The sample container was a polyethylene-type plastic. Labeled samples in airtight bottles were put into boxes containing ice blocks and transported to the laboratory for storage at 4°C before analysis. River discharge (Q, m^3/s), water temperature (T, °C), and dissolved oxygen (DO, mg/L) were measured in situ. Turbidity (mg/L) and TSS (mg/L) were measured directly after sampling

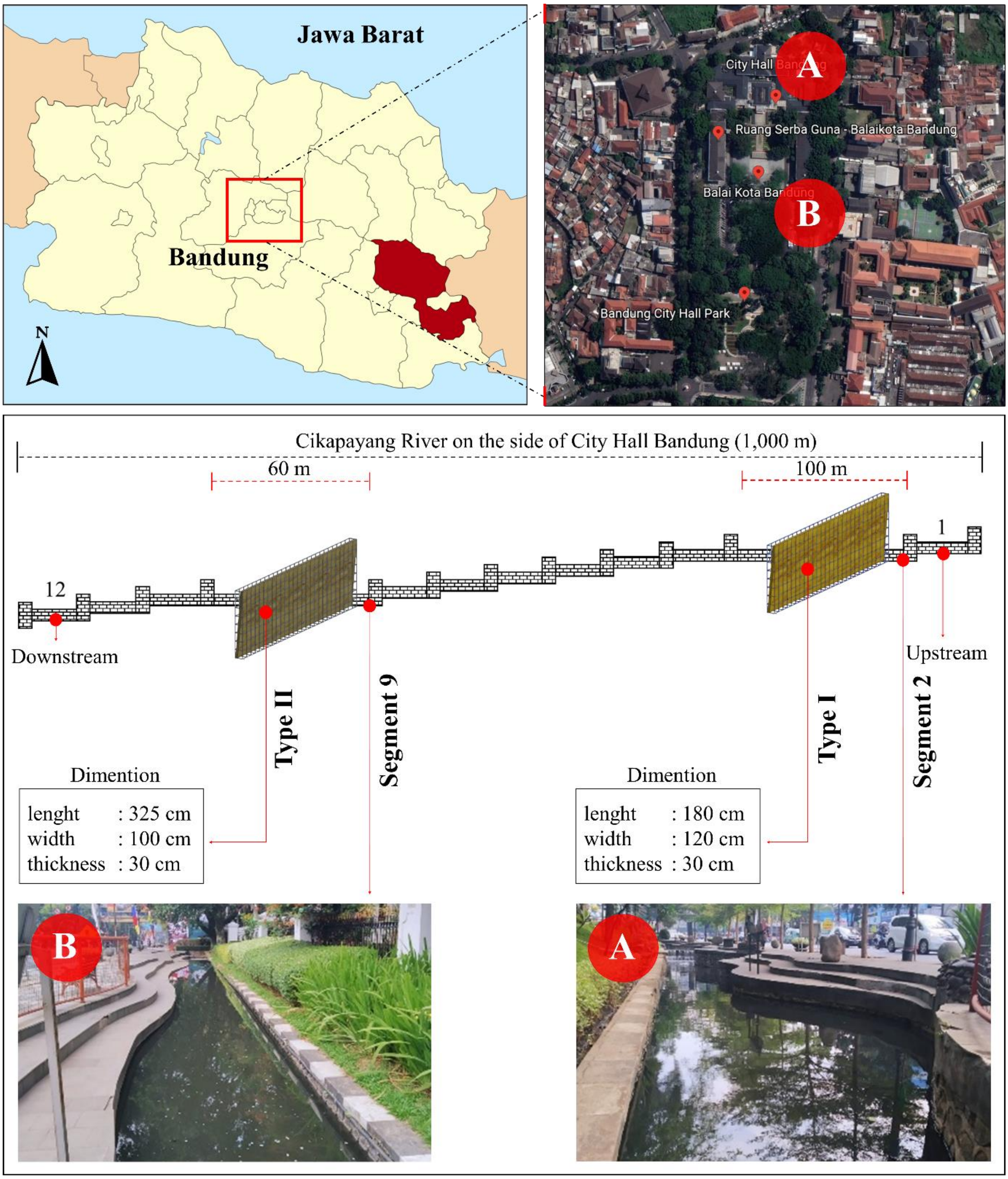

Figure 1. Research location: mineral wool type I at segment 2 (107º36′37.8″E 6º54′37.5″S) and mineral wool type II at segment 9 (107º36′37.3″E 6º54′44″S)

in the laboratory. The temperature was measured using the Water Analyzer Meter EZ-9908, DO using the DO Meter Digital HACH HQ40D, and turbidity using Turbidity Portable Meter WTW 355IR, while TSS used the SMEWW 2540 B method with gravimetric principle. A sample of 250 mL was filtered using Whatman filter paper (no. 42) 2.5 µm pore size with diameter of 125 mm and a vacuum pump. Then, a Memmert Oven UN55 53 L was used to dry the filter and placed in a 90 mm porcelain bowl for 60 min at 105ºC. The bowl was dried in the same oven to get the original weight. TSS concentration was calculated by weighing the solids in a dry bowl. The filter paper depicted the total solids representing the TSS concentration of the water sample (mg/L). Samples were analyzed in duplicate.

2.4 Data analysis

The measurements of TSS were compared with the river water quality standard by Indonesian Government Regulation 81 of 2001, Class II. TSS removal efficiency in Cikapayang River (%) by mineral wool was determined using the Equation (1). Here, RE is the removal efficiency (%), $C_{influent}$ is the initial TSS concentration (mg/L), an $C_{effluent}$ is the TSS concentration after the treatment using mineral wool (mg/L).

$$RE = \left(\frac{C_{influent} - C_{effluent}}{C_{influent}}\right) \times 100\% \quad (1)$$

Scanning Electron Microscope Energy Dispersive X-Ray (SEM-EDX) was used to identify and characterize materials to observe reactions around interfaces and the elemental composition of mineral wool specimens. The One Way ANOVA is used in this study to test the differences in TSS concentrations in different seasons using the RStudio Cloud software.

3. RESULTS AND DISCUSSION

3.1 River water quality

In this study, Q, T, DO, and turbidity data could identify the TSS concentration affecting aquatic conditions. A total of 19 samples of 10 sampling periods resulted in high concentrations of TSS, which exceeded the standard (50 mg/L). Eighty-nine percent of them were the result of measurements in the dry season. Suspended solids distribution in the Cikapayang River in this season increased by 41%. In comparison, the turbidity in the rainy season ranges from 7-121 mg/L (average of 28 mg/L). The increase in turbidity is the impact of increasing the concentration of TSS from non-natural sources (Hern et al., 2014). The change of seasons causes the water turbidity to increase by 14%. The average water temperature is reduced by 2% during the rainy season. Table 2 presents the range of parameters values and standard deviations of the TSS and other related parameters based on the analysis results on segments 2 and 9 before passing through the mineral wool.

Table 2. Water quality characteristics of Cikapayang River

Parameter	Unit	Standard[a]	Sampling result				Deviation (%)	Annual average
			Rainy season		Dry season			
			Range	Average	Range	Average		
Q	m^3/s	-	0.15-1.56	0.40	0.09-0.67	0.24	15	0.31
T	ºC	25-27	21.12-25.85	24.21	21.98-25.24	23.72	2	23.95
Turbidity	NTU	-	7-121	28	11-150	32	14	27
DO	mg/L	>4	0.5-5.1	2.6	0.1-0.9	0.2	92	2.3
TSS	mg/L	50	7-121	27	10-118	58	41	35

[a]Government of the Republic of Indonesia (2001)

The average DO concentration in the dry season decreased significantly from 2.6 mg/L to only 0.2 mg/L. In other words, DO has declined by 92% compared to the rainy season. Water plants and algae produce oxygen during the daytime photosynthetic process, and this cycle occurs every day, while the oxygen is used for organic matter decomposition by microbial communities. Hence, dead aquatic plants and the increasing amount of pollutants in the water cause a massive reduction of DO (Zhang et al., 2018). Water temperature decrease is significant in June-July, even though this period shows no rain. The average air temperature increased by 4ºC from 21ºC, but the water temperature decreased (0.2-1.5ºC). Shinohara et al. (2021) reveal that surface water temperature is more sensitive to changes in shortwave radiation. Still, this theory does not occur in the Cikapayang River, whose conditions have changed significantly due to input from outside the system. Other factors such as groundwater ingress and heat conduction absorption by the system may affect the surface water temperature. However, in this case, suspended solids that block solar radiation appear to be the main factor responsible for the decrease in surface water temperature. The water temperature decreases significantly when the water discharge shrinks by 15%.

3.2 Effects of seasons and mineral wool types in TSS removal

TSS concentrations in both segments correlated with mineral wool's TSS removal capability in each segment, shown in Figures 2(a) and 2(b). River water quality in the dry season showed a narrower range of parameter values than during the rainy season, but the concentration of pollutants increased. Rainwater entering the river has a conductivity lower than 100 s/cm (Makineci et al., 2015) and is diluted due to mixing with polar ions and molecules so that the TSS concentration measured in the rainy season tends to produce a lower average.

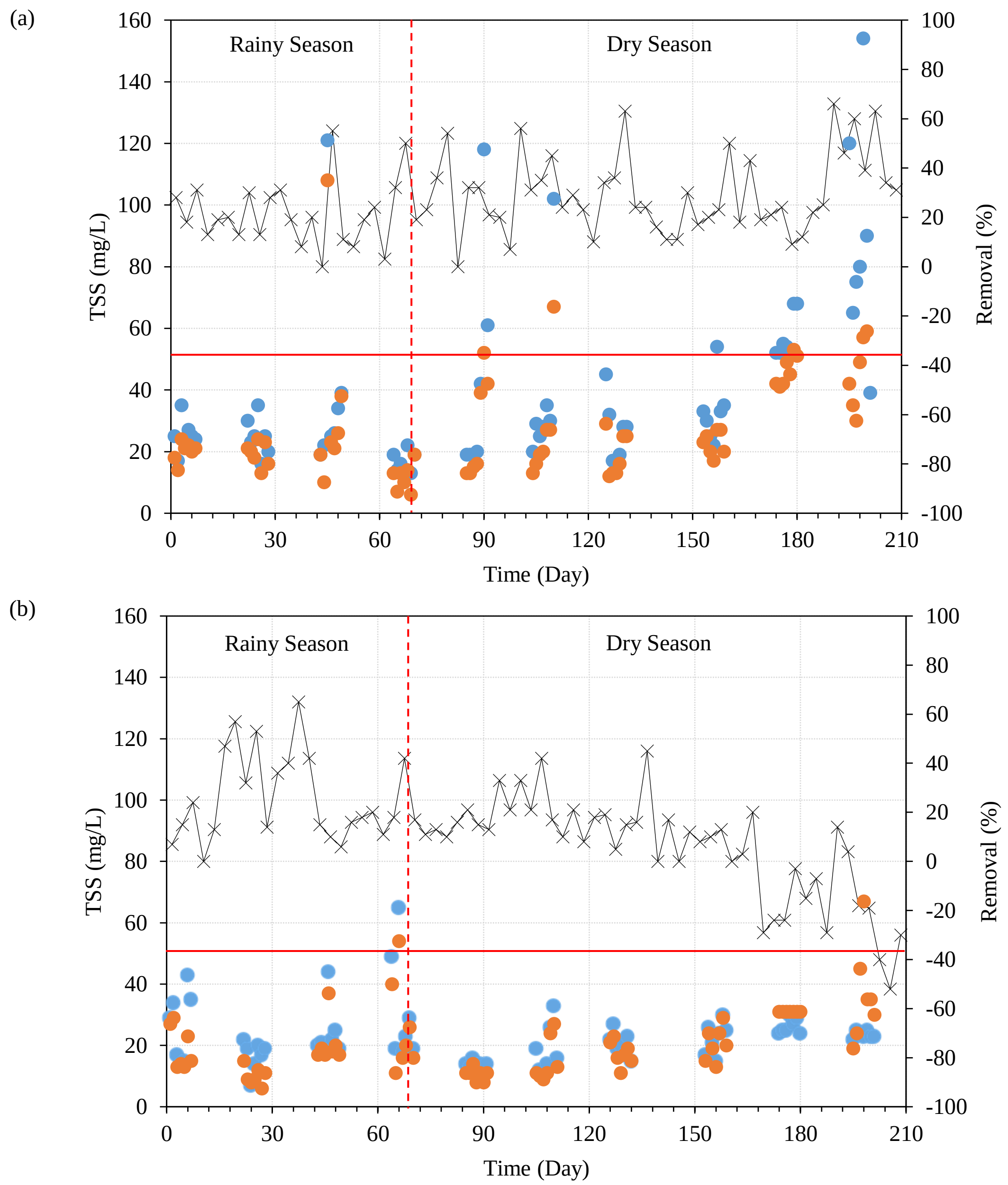

Figure 2. Concentrations of TSS before and after passing mineral wool (a) type I and (b) type II

The average TSS removal efficiency for type I was 31.43% and 14.71% for type II. The best efficiency reached 65% filtered by mineral wool type I. The high concentration of TSS before passing through the media during the dry season caused the removal ability by type I mineral wool in segment 2 to increase by 6.82%. The slowing flow velocity influenced this medium's increase in removal capacity, which caused the contact between suspended solids and the fibers' media to be more optimum. The efficiency of removal by small media in segment 9 was affected by any limiting factors. Suspended solids with a specific gravity higher than the density of water settled and collected on the surface. The solids could then be pulled up during sampling. This then caused the TSS removal ability by type II mineral wool to be lower when compared to type I (Figure 3).

Land-use change in Bandung City causes the terrestrial runoff coefficient on Cikapayang River to have increased from 70.98 mm to 72.04 mm over the last two decades (Atharinafi et al., 2021). As a result, surface terrestrial runoff increased from 48.98 mm in 1999 to 51.8 mm in 2018. Terrestrial runoff permeates into the river, causing the measured water level upstream to increase, while in the downstream (segment 9), the water level tends to be consistent due to the presence of manual discharge control by the presence of bulkheads between segments. The new water flow would run over after reaching the maximum height limit on the insulating wall. The water level in the rainy and dry seasons had a difference of 50 cm in the upstream area. However, the water level in the dry season was mixed with solid particles, so measuring the water volume in segment 2 was complicated. Figure 3 depicts the difference between the minimum, maximum, and average values from two seasons before and after flowing through mineral wool. The concentration of TSS is higher during the dry season, in contrast to Leong et al. (2017), who said that more solids would be found during the rainy season. Based on this fact, domestic wastewater has a more significant influence on TSS concentration in Cikapayang River than the solids contained in the terrestrial runoff. As illustrated in Figure 4, the water velocity significantly affects the media's ability to remove TSS. The river elevation as a restoration result makes this more likely, where the large volume of water creates a downstream push so that the velocity naturally increases. Suspended solids that do not get a strong push by the flow will be held by the media and make it trapped on the surface of the media. In the rainy season, some suspended solids are resuspended due to the impulse by the water velocity that suddenly increases when it rains. It is why the dry season removal efficiency shows higher efficiency.

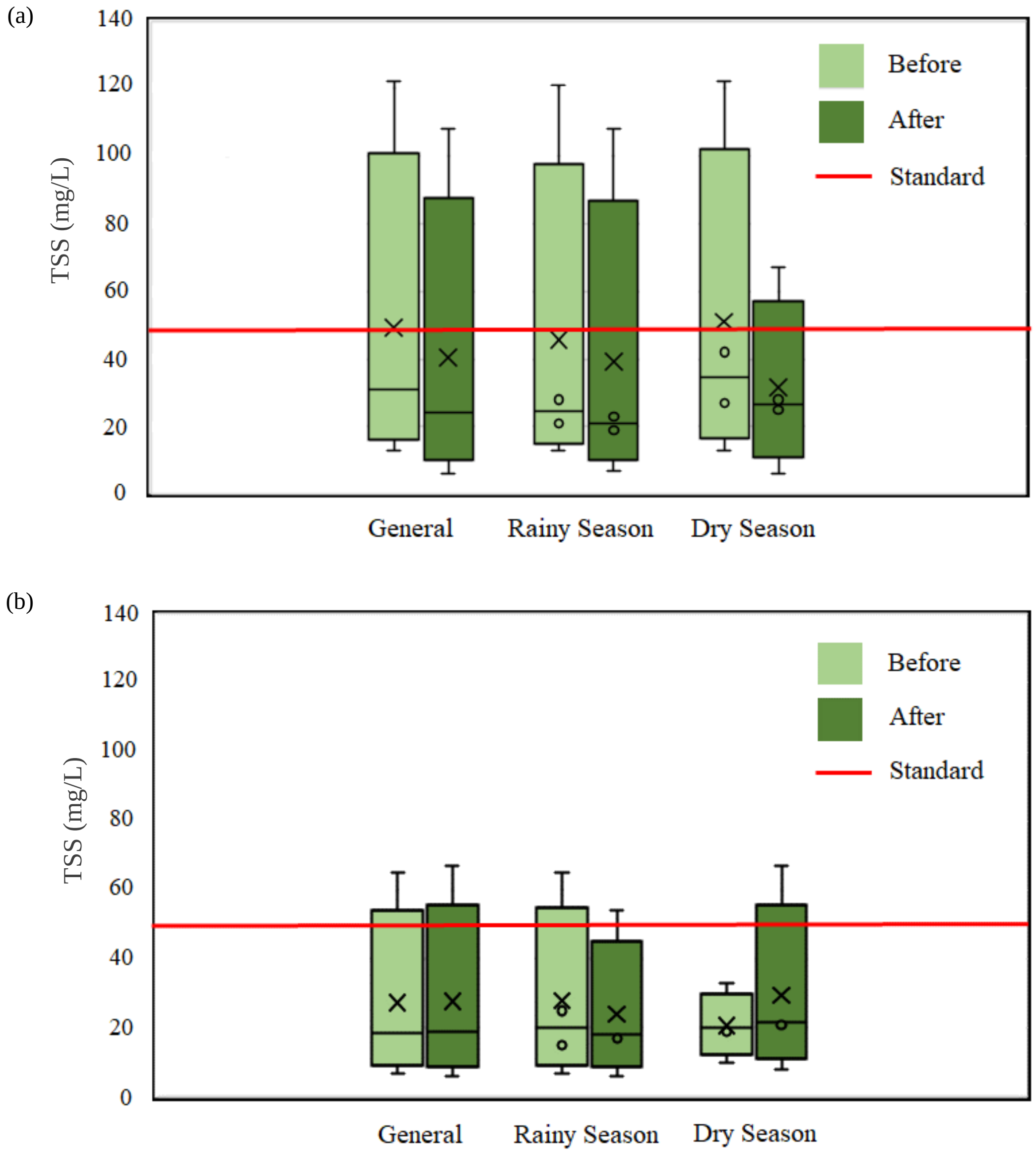

Figure 3. Concentrations of TSS before-after passing mineral wool (a) type I and (b) type II in rainy and dry seasons

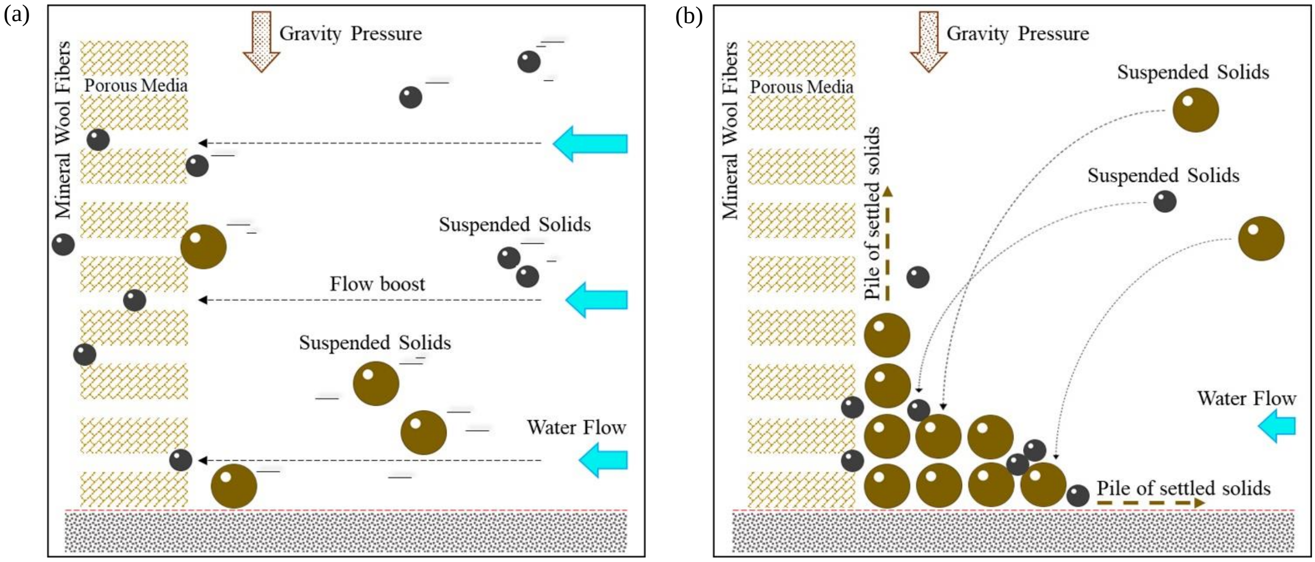

Figure 4. (a) The large volume of the river in the rainy season causes the velocity to increase significantly, and suspended solids resuspension due to a strong push from water flow (b) Slow water flow in the dry season causes suspended solids to accumulate

The ANOVA test results to see the differences in TSS concentrations in different seasons is presented in Table 3. In segment 2, using mineral wool type I, the probability value of F is 0.0000104, where this value is smaller than 0.05. So, it can be concluded that there is a difference in the TSS concentration value in different seasons. However, as for mineral wool type II, the probability value of F obtained is 0.91 (>0.05), which means that it can be concluded that there is no statistical difference between TSS concentrations in different seasons. This is because there is a different pattern in each mineral wool type, as seen in Figure 4, whereas in mineral wool type II, the TSS removal is lower. It the more stable in both seasons because the flow in segment 2 is only affected from upstream. Measured debits are not much different between seasons (only 5%). While segment 2, which is the upstream part of the river, is strongly influenced by fluctuations in various previous flows. The difference in flow rate is very visible, where there is a decrease of 31% during the dry season. Even this value is not the real value because when measuring the water depth, the physical river tends to be filled with piles of mud more than the flow of water.

Table 3. TSS concentrations in different seasons by ANOVA test

Mineral wool	Pr (>F)	Significance level (α)	Conclusion
Type I	0.0000104	0.05	H_0 rejected
Type II	0.921	0.05	H_0 accepted

3.3 SEM-EDX analysis of mineral wool

Two forms of fiber make up mineral wool, namely dangling lacunar and spherical fibers. The spherical shape is formed when the fiber formation is not perfect during production process (Wanko et al., 2016). Based on Figure 5, the morphological spectrum in type I illustrated that the constituent fibers were more systematic than in type II, while the constituent fibers of type II were shorter in size. The more regular and perfect shape caused the gaps between the fibers to widen, allowing more solids in the flow to get caught in the lacunar yarn cavities. SEM analysis showed that the lacunar fiber size in type I had a diameter of 10-20 μm and a spherical shape with a diameter of 75-100 μm. Type II lacunar fibers were 5-15 μm in diameter, while spherical fibers were 80-200 μm in diameter.

The main compounds of mineral wool fibers consist of SiO_2 and Al_2O_3 (Chen et al., 2017). Differences in the chemical composition of the surface of the degraded media correlated with the different TSS removal capabilities between the types. Inorganic elements such as Mg, Al, Si, Ca, and Fe are the main constituents of mineral wool with a total composition of 98%. The high content of Mg, Al, Ca, and Fe from media caused it to be different from other types of wool, such as rock wool, where 59-64% Si is the main constituent element (Yliniemi et al., 2021). The high mineral content makes this type of wool called mineral wool. The TSS analysis showed a correlation between the composition of the media and the removal efficiency, as shown in Figure 6. The high element of carbon (C) in mineral wool type I indicated the optimal ability of the media to remove organic matter. Type I mineral wool that had been set up until the 201st day had an elemental C of 34.81%. The high content of carbon gives an idea of the high level of roughness of the media, thus making the substrate in the water body easily attached due to the large frictional force. Mineral wool type II consisted of 3.61% Mg; 2.84% Al; 10.40% Ca; and 4.86% Fe. The Si content in this type reaches 7.17%, while it is only 5.80% in type I. The results of the SEM EDX test found that the total difference in mineral composition in type I was 13.36% lower than in type II. This phenomenon indicates that the mineral content in the media should give more optimal results. Still, very high solids in the upstream resulted in the removal rate as if the mineral wool type I was better.

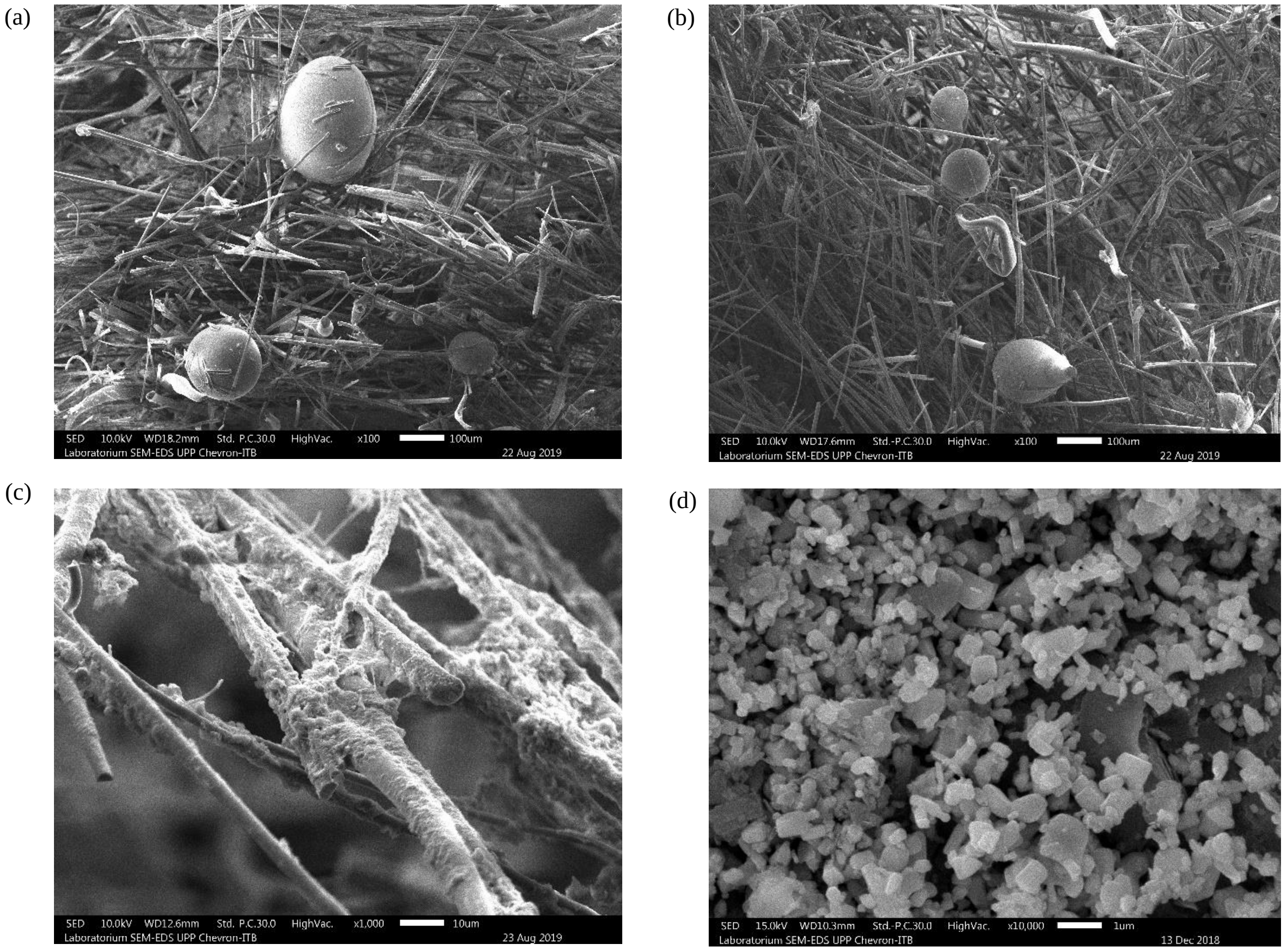

Figure 5. SEM images of mineral wool (a) type I before used, (b) type II before used, (c) after used at 1,000x magnification, and (d) after used at 10,000x magnification

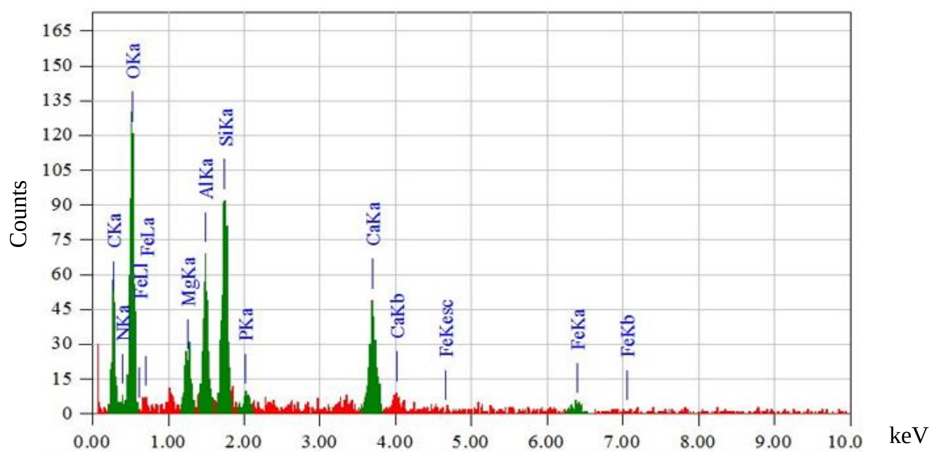

Figure 6. Composition of mineral wool (a) type I and (b) type II, after 201 days

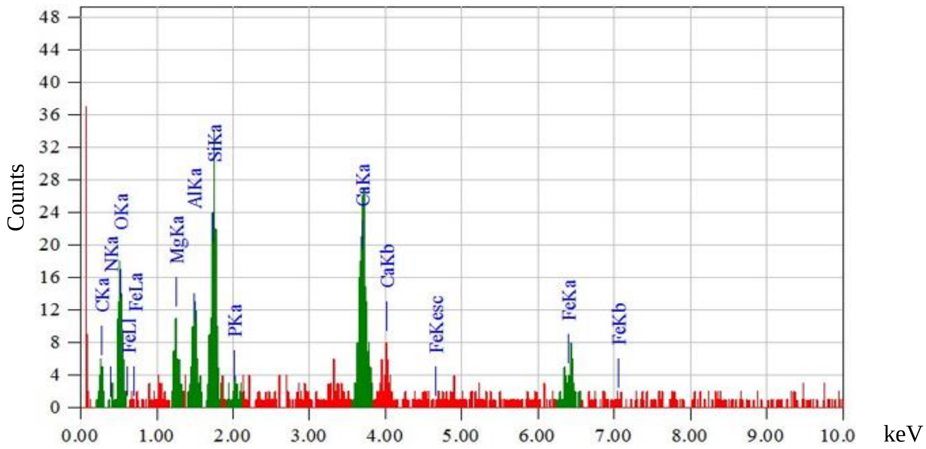

Figure 6. Composition of mineral wool (a) type I and (b) type II, after 201 days (cont.)

4. CONCLUSION

Mineral wool as a filter medium has proven to reduce some TSS concentration in Cikapayang River. The broader surface of the filter media is very relevant for optimal removal of TSS because its surface interacts with suspended solids in the water flow and the number of lacunar fibers that absorb solids increases. The higher mineral concentration as the composition of the constituent elements of each type was positively correlated with the ability of the media to remove TSS material in water bodies. The high concentration of TSS in segment 2 as the upstream of Cikapayang River at City Hall Bandung made it challenging to identify the effect of mineral composition on the media on the TSS removal ability. The environment of the river system between segment 2 and 9, including the difference in TSS concentration in each segment, made it tough to compare the capabilities of the media with each other. However, based on this experiment, mineral wool could be applied as an on-site supporting material to address river pollution in urban areas prone to urbanization due to the lack of domestic wastewater treatment facilities and public awareness. There are quite a lot of studies on mineral wool, but studies in water treatment applications are still very limited. In the future, removal of chemical and biological parameters, kinetics modeling, and economic analyses of the mineral wool use are priorities to analyze the feasibility of this medium comprehensively.

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