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Mequannt Marie, Fikadu Yirga, Mebrahtu Haile, Filmon Tquabo

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Huei-Hwa Lai, Szu-Hsien Lin

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Samara T. Leite, Fernando H. do Nascimento, Jorge C. Masini

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Anastasia Rita Widiarti, Reza Pulungan

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Rocio Geng Vivanco, Renata Silva Cardoso, Ana Beatriz Silva Sousa, Michelle Alexandra Chinelatti, ... Fernanda de Carvalho Panzeri Pires-de-Souza

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Nankie M. Ramabu

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Zeleke Tesema, Belay Deribe, Alemu Kefale, Mesin Lakew, ... Liuel Yizengaw

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18

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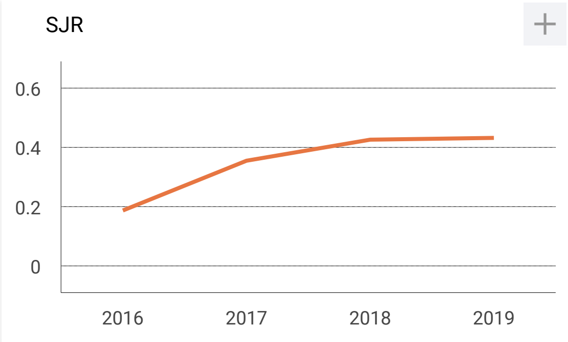

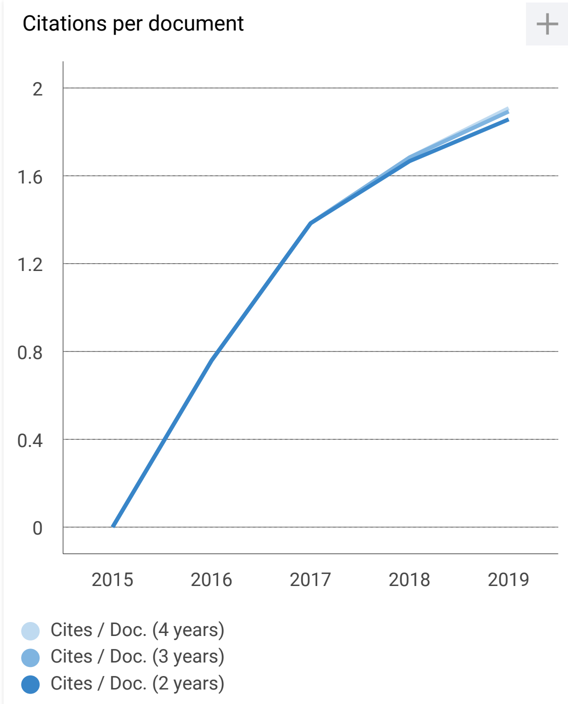

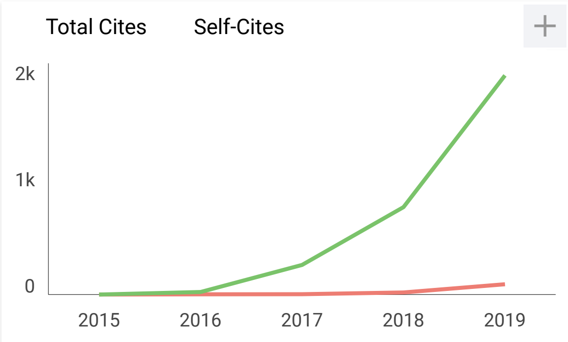

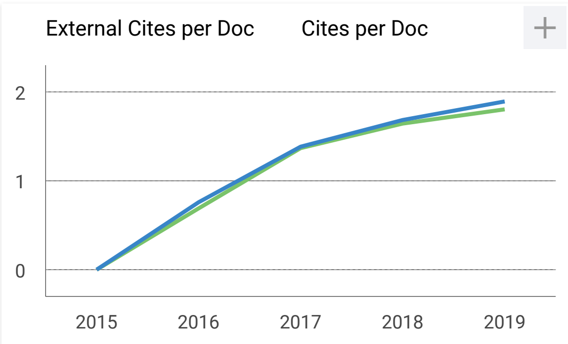

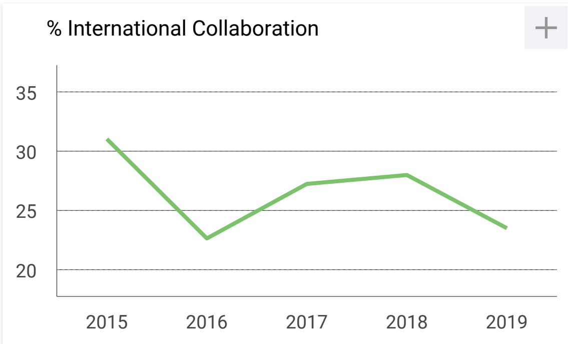

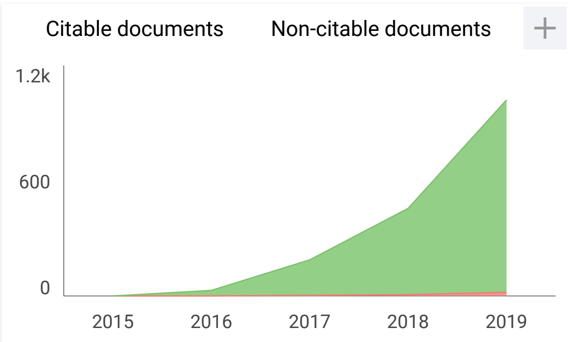

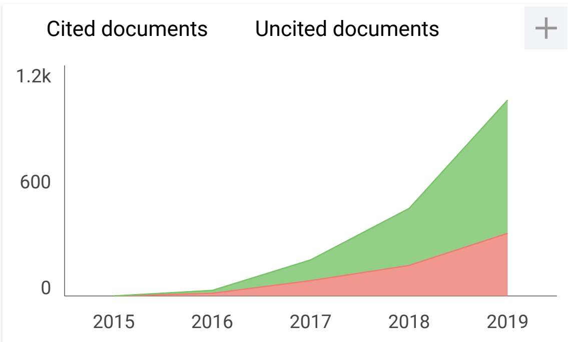

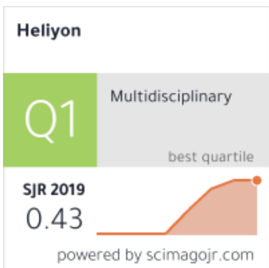

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Heliyon 6 (2020) e03736

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Research article

Behavior of *schmutzdecke* with varied filtration rates of slow sand filter to remove total coliforms

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ARTICLE INFO

Keywords:
Chemical engineering
Environmental science
Environmental analysis
Environmental engineering
Water treatment
Waste
Water quality
Drinking water
Schmutzdecke
Slow sand filter
Total coliforms

ABSTRACT

The previous research showed that slow sand filtration (SSF) can remove the total coli by approximately 99% because of the *schmutzecke* layer in the filter. The presented study aimed to complete the previous research on SSF, especially on the *schmuztdecke* layer mechanism, to remove total coli. Total coli is a parameter of water quality standard in Indonesia, and the behavior of *schmutzdecke* affects the total coli removal. In the present study, the raw water from Amprong River was treated using horizontal roughing filter (HRF) and SSF. The variations in SSF rate used were 0.2 and 0.4 m/h. Total coliforms were analyzed using the most probable number test, and *schmutzdecke* visualization was conducted through scanning electron microscopy–energy-dispersive X-ray spectroscopy (SEM–EDX). The best coliform concentration in water treated by the combination of HRF and SSF was 4,386 colonies per 100 mL of sample using the filtration rate of 0.2 m/h, and its removal efficiency was 99.60%. However, the quality of water treated by the combination of HRF and SSF did not meet the drinking water quality standard because the removal of total coli must be 100%. The SEM–EDX visualization results in *schmutzdecke* showed that the average bacteria in the *schmutzdecke* layer were small, white, opaque, and circular, with entire edge and flat elevation. The Gram test results showed that the *schmutzdecke* bacteria consisted of Gram-positive and Gram-negative bacteria with basil as the common cell form.

1. Introduction

The demand for drinking water continuously increases. Regional Drinking Water Company (PDAM) as an agency that supplies drinking water constantly attempts to find new sources of water to fulfill the community's demand of drinking water. One method taken by PDAM is by utilizing river water as a source of raw water. River water must be first treated to meet quality standards before being used as drinking water. An alternative method to convert river water into raw water for drinking is by using roughing and slow sand filters which is an old and successful treatment, especially for drinking water in rural areas (Rooklidge et al., 2005).

The present study aims to complete other research about slow sand filtration (SSF), especially on the *schmutzdecke* layer that influences the biological process mechanism. The novelty of this research is the behavior of *schmutzdecke* to remove total coli in river water. The previous research showed that schmutzdecke can remove *Escherichia coli* (*E. coli*) (Balen, 2018). Soil filtration system known as sand filter is extremely efficient for removing pathogens (Ellis, 1985; Hijnen et al., 2004). Some studies have explained the relationship between biological activities and bacterial removal during SSF (Bellamy et al., 1985; Unger and Collins, 2008; Balen, 2018). The microorganisms formed in *schmutzdecke* are influenced by the treated raw water.

A study on roughing and slow sand filters was conducted by Sarwono et al. (2017). In this study, they used horizontal roughing filter (HRF) and vertical roughing filter and achieved total coliform removal efficiencies of 93.32% and 94%, respectively (Nkwonta and Ochieng, 2009). The results Khumalasari and Hadi's study (2010) showed that the largest decrease in total coliforms using roughing filter is 88.23%, whereas the decrease using slow sand filter unit is 99.95%.

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https://doi.org/10.1016/j.heliyon.2020.e03736
Received 7 December 2019; Received in revised form 14 February 2020; Accepted 31 March 2020

The present study consisted of two variations, where the first variation is the type of roughing filter, and the second is the filtration rate of slow sand filter. Amprong River water treated using roughing filter and slow sand filter reactors were observed for its biological parameter, that is, the number of total coliforms. The number of total coliforms contained in the water treated by the reactors was compared with the quality standards stipulated on the Regulation of the Ministry of Health of the Republic of Indonesia Number 492/Menkes/Per/IV/2010 on the Quality Standards of Drinking Water to determine whether the treated water can be used as drinking water. The removal efficiency was measured to determine the reactors' effectivity in reducing the total coliforms.

Water treatment inside the slow sand filter unit occurs in the *schmutzdecke* layer. *Schmutzdecke* is a biological layer found in the surface of slow sand filter (Ranjan and Manjet, 2018). The study of bacteria in the *schmutzdecke* layer was conducted to determine the types of bacteria that live in it.

2. Research method

2.1. Place and time

The study was conducted at the Amprong River as the point of raw water sampling and in the official residence of PDAM Wendit Spring, which is the place where the roughing filter and slow sand filter reactors were placed. The Amprong River is located in Malang City, Indonesia, as shown in Figure 1. Most probable number (MPN) test and bacteria identification in the *schmutzdecke* layer were performed at the Integrated Laboratory of the Faculty of Science and Technology Universitas Airlangga. The study was conducted from March to June 2019.

2.2. Tools and materials

The tools used to take Amprong River water samples were bucket, jerrycan, and 300-L water tank. The tools for roughing filter and slow sand filter reactors included acrylic plate with 0.75 cm thickness, a pump, PVC pipes with mesh sizes of 40, 60, and 100, a swivel faucet, measuring cups, and a stopwatch. Test tubes, durham tubes, media bottles, analytical scale, volume pipettes, test tube holders, petri dishes, cotton, ose needle, matches, marker, vortex, autoclave, and spirit lamps were utilized in the MPN test and bacteria isolation.

The main material used in this study was raw water taken from the Amprong River. The materials used for roughing filter reactors were gravels with diameters of 10, 20, and 30 mm. The materials utilized for slow sand filter reactors were fine sand with diameter of 0.15–0.595 mm and gravels with diameter of 10–30 mm. The materials used for the MPN test and bacterial isolation and identification included Amprong River water, distilled water, lactose broth media, Brilliant Green Bile Broth media, nutrient agar media, cling film, cotton, aluminum foil, 70% alcohol, and rubbing alcohol.

2.3. Raw water supply

The Amprong River supplied raw water in this study. Raw water supply should be adequate because the reactors continuously operated for 24 h. The daily need of raw water was calculated.

2.4. Stage I

The types of roughing filters used were vertical roughing filter and HRF. They were utilized at a filtration rate of 0.4 m/h. Water discharge in the first stage was 4.16 mL/s. The sample in this stage was taken once every day for 10 days. The effluent of the two reactors were contained in a container tank to analyze its total coliforms. The sampling and parameter testing of reactor effluent were conducted once every other day.

2.5. Seeding and acclimatization of filter media

Seeding aims to grow microorganisms on the filter media. Seeding was conducted by continuously flowing Amprong River water into the reactor for 3 days. Acclimatization was used on the microorganisms that grow in the filter media to adjust to their new environment, enabling them to achieve a stable condition. The seeding observed every day showed the growth of the *schmutzdecke* layer in the form of a brownish slimy layer.

2.6. Stage II

The reactors were operated by flowing Amprong River water into the HRF unit. The effluent of the unit's treatment was then flowed into a containment tank to be tested for its total coliforms. After the test, the

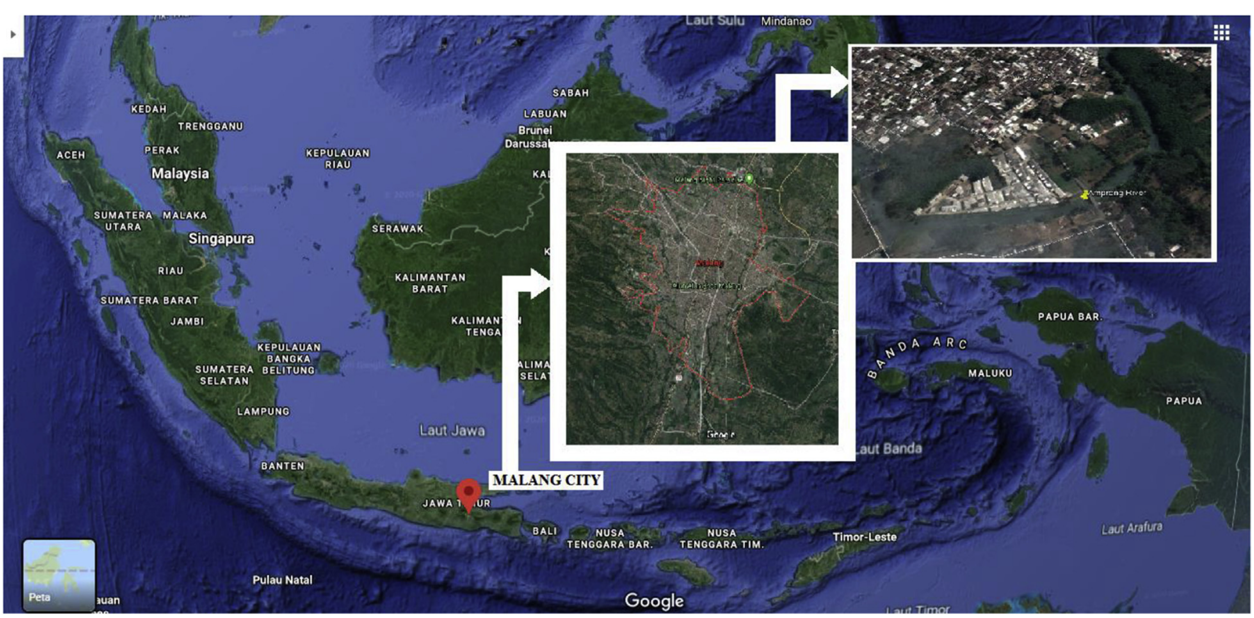


Figure 1. Location of the Amprong River (Source: Google Earth).

Table 1. Total coliforms in roughing filter.

Day	Inlet		Outlet	
	HRF	VRF	HRF	VRF
	Before treatment	Before treatment	After treatment	After treatment
0.	1,100,000	1,100,000	67,000	110,000
3.	1,100,000	1,100,000	78,000	67,000
5.	1,100,000	1,100,000	62,500	78,000
7.	1,100,000	1,100,000	46,000	60,500
9.	1,100,000	1,100,000	110,000	65,500
Average	1,100,000	1,100,000	72,700	76,200

effluent water was flowed into the slow sand filter units with the filtration rates of 0.2 and 0.4 m/h. In the second stage, the discharge of slow sand filter with filtration rate of 0.2 m/h was 1.15 mL/s, and that of the slow sand filter with 0.4 m/h filtration rate was 2.3 mL/s. The effluent of slow sand filter units flowed into the containment tank to be tested for its coliforms. The samples were tested once a day. The effluent of each slow sand filter unit was analyzed for 10 days. The sampling and analysis of each reactor's effluent was conducted every other day.

2.7. MPN test

MPN test was conducted by taking samples from the inlet and outlet of each reactor unit. The sample was taken and repeated twice. The water sample taken was 100 mL. The MPN test consists of two tests, namely, presumptive and confirmed tests. The MPN method applied was the MPN 3-3-3 in test tubes.

2.8. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) analyses

A sterilized spatula was used to take a sample from the *schmutzdecke* layer in slow sand filters for the SEM–EDX test. The sample was taken from one point with the depth of 0.1 cm for 1 g. For the imaging and composition data, the sample was oxidized using SEM tools and was placed and stuck on SEM specimen holder using double tape.

2.9. Identification of types of bacteria on the schmutzdecke layer

The macroscopic characteristics of bacterial colony observed included the size (growth abundance), pigmentation, shape, edge, and elevation of bacterial colony. The microscopic characteristics of the bacteria were observed with a microscope to determine their cell shape and whether they are Gram-negative or Gram-positive bacteria.

3. Results and discussion

3.1. Concentration and coliform removal efficiency of roughing filters with varying flow directions

The results of biological concentration (total coliforms) in the effluent treated using roughing filter with varying flow directions are shown in Table 1.

The number of total coliforms in the outlet of horizontal and vertical roughing filters fluctuated on the basis of the analysis results in Table 1. The sample was 100 mL, and the sampling time was twice a day. Horizontal and vertical roughing filters were applied to separate the solids from raw water. Solid separation in water occurs because of sedimentation and filtration. This process is the main process that occurs in roughing filters (Wegelin, 1996). A roughing filter is a physical filtration unit used to reduce the mass of solids (Khumalasari and Hadi, 2010). However, the use of roughing filter is not optimal in reducing the number of bacteria or total coliforms during the first stage of this study.

The coliform removal efficiency of roughing filter units is shown in Figure 2.

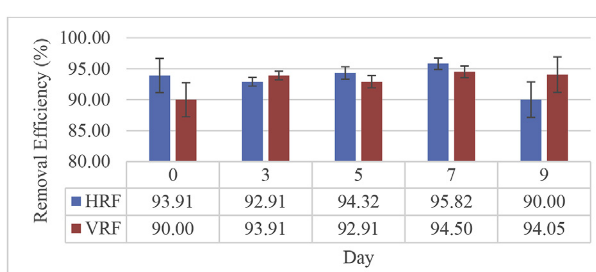
As shown in Figure 2, the coliform removal efficiency of HRF and vertical roughing filter were 93.91% and 90%, respectively, during the first day of operation. The final efficiency results of HRF and vertical roughing filter on average were 93.39% and 93.07%, respectively. In the roughing filter, suspended solids that are larger than the pores of gravel media as the filter, such as leaves, small stones, and rubbish debris, are filtered (Wegelin, 1996). Screening or particle filtration is continued with sedimentation to be sedimented on the media surface. The last stage of water treatment in roughing filter units is interception, which is a process to enhance the removal rate of a roughing filter. Nonoptimal coliform removal of roughing filter occurs because of the reactor's ineffectiveness in the screening process. The majority of bacteria can still evade the screening process because their size is smaller than the diameter of the filter media. The diameter of bacteria is approximately 0.5–1.0 μm (Pelczar and Chan, 2013).

Normality test results showed that the removal efficiencies of HRF and vertical roughing filter were 0.694 and 0.098, respectively. The significance values signified that the data on two reactors were homogenous because they were larger than 0.05. The independent T-test sample showed a significance value of 0.808. The significance value larger than 0.05 indicated no difference between the two reactors in removing coliforms. The absence of difference between HRF and vertical roughing filter reactors in removing total coliforms may be caused by the similar time of contact between raw water and media filter during treatments, which were 58 and 62 min.

3.2. Coliform concentration and removal efficiency of the chosen roughing filter combined with slow sand filters with varying filtration rates

The biological concentration (total coliforms) in slow sand filter is shown in Table 2.

The slow sand filter with 0.2 m/h filtration rate initially reduced the average number of total coliforms to 4,386 per 100 mL from the total of 1.1×10^5 per 100 mL sample. By contrast, the slow sand filter with 0.4 m/h filtration rate initially decreased the total coliforms to 6,219 per 100



	0	3	5	7	9
HRF	93.91	92.91	94.32	95.82	90.00
VRF	90.00	93.91	92.91	94.50	94.05

Figure 2. Coliform removal efficiency of roughing filter.

Table 2. Total coliforms in slow sand filter.

Day	0.2 m/h SSF		0.4 m/h SSF	
	Inlet	Outlet	Inlet	Outlet
0.	110,000	410	110,000	865
3.	110,000	7,800	110,000	11,000
5.	110,000	2,420	110,000	11,000
7.	110,000	4,600	110,000	430
9.	110,000	6,700	110,000	7,800
Average	110,000	4,386	110,000	6,219

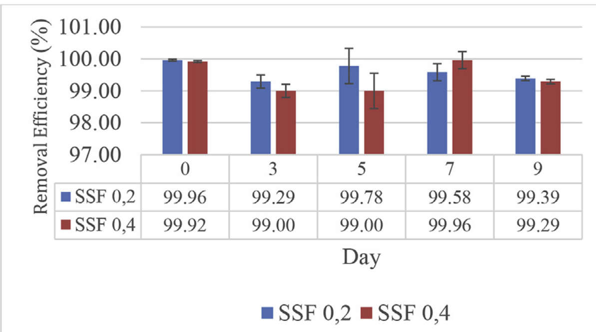


Figure 3. Coliform removal efficiency of slow sand filter.

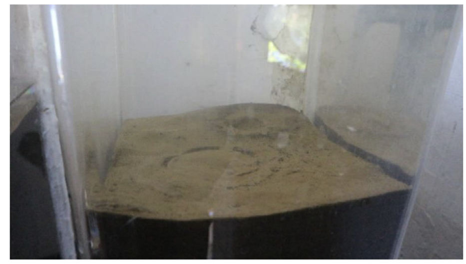


Figure 4. *Schmutzdecke* layer in slow sand filter.

mL from the total of 1.1×10^5 per 100 mL of sample. The coliform removal efficiencies of slow sand filters with filtration rates of 0.2 and 0.4 m/h are presented in Figure 3.

As shown in Figure 3, the average coliform removal efficiencies of slow sand filters with 0.2 and 0.4 m/h filtration rates were 99.60% and 99.43%, respectively. The coliform removal efficiency of slow sand filter reactors was relatively the same. This result is in accordance with the research conducted by Balen (2018), where the adenosine triphosphate (ATP) concentration (the quantification of active biomass in *schmutzdecke*) correlated with *E. coli* removal. *E. coli* removal increased with high ATP concentration during filtration for 3 weeks (Balen, 2018). Similar results were obtained by Jawaduddin et al. (2019), although the total coli removal in FeCl3-based activated carbon combined with sand filter reached 97.9%.

Three filtration mechanisms of slow sand filter, namely, physical, chemical, and biological mechanisms, are found in removing contaminant particles that come from raw water. The main process of the filtration mechanism is mechanical straining. Mechanical straining causes particles to be trapped in the filter media because their particle size is larger than the size of the media. The cavity between the filter media becomes small because of the restrained particles, and the particles are then removed (Donison, 2004).

Sedimentation occurs because particles are deposited on the surface of filter media. The particles contained in water combine with other particles when the water goes through the filter media. The particles are then deposited and restrained by the filter media in the form of sand (Huisman and Wood, 1974).

Adsorption functions to remove small particles from the suspended particles. The formation of *schmutzdecke* begins with the development of microorganisms on the surface of sand grains, thereby providing an adsorptive surface for the attachment of organic matter in the water (Hendricks et al., 1991). This condition occurs because of different particle charges between the suspended particles and media filter surface. Colloidal particles are positively charged, whereas sand is negatively charged. The positive charge of particles is accumulated on the sand surface, thereby leading to saturation. The thicker the dirt on the media filter surface is, the lower the adsorption energy will be.

Dissolved particles are converted into simple substances because of chemical activities. Chemical activities make these decomposed particles harmless: thus, they can be removed through screening, sedimentation, and adsorption in the filter media (Huisman and Wood, 1974). Biological mechanism that occurs in slow sand filter is affected by the *schmutzdecke* layer. The decrease in total bacteria is because of the removal on the *schmutzdecke* layer (Verma et al., 2017). Most suspended particles and organic materials are decomposed on the *schmutzdecke* layer (Suryadi, 2014). This layer is a brownish layer with thickness of 0.2 cm that is formed in a slow sand filter. The *schmutzdecke* layer formed in the slow sand filter is shown in Figure 4.

Particles in raw water go through the sand media filter. The restrained particles become food for the bacteria on the *schmutzdecke* layer. The reactor will be clogged when excessive pollutants are restrained in the sand media. Thus, the water from the inlet channel cannot flow through the outlet channel. Scrapping by taking the sand media with 2 cm depth is conducted to improve the performance of slow sand filter after clogging.

The efficiency of slow sand filter in removing total coliforms is assessed on the basis of contact time and filtration rate. A study conducted by Ranjan and Manjet (2018) showed that the efficiency of slow sand filter in removing bacteria in water depends on the contact time between water and filter media. The contact time of slow sand filter with 0.2 m/h filtration rate is longer than that of slow sand filter with 0.4 m/h filtration rate. The higher the filtration rate is, the more scrapping processes are conducted. Excessive scrapping will damage the *schmutzdecke* layer, thereby preventing the biological removal to function efficiently (Khumalasari and Hadi, 2010).

Table 3. Comparison between water quality treated with HRF–SSF reactor and quality standards.

Parameter	HRF Inlet (Raw Water)	HRF Outlet	0.2 m/h SSF Outlet	0.4 m/h SSF Outlet	Regulation of the Indonesian Health Minister No. 492 of 2010
Total coliforms (per 100 mL of sample)	1,100,000	110,000	4,486	6,219	0

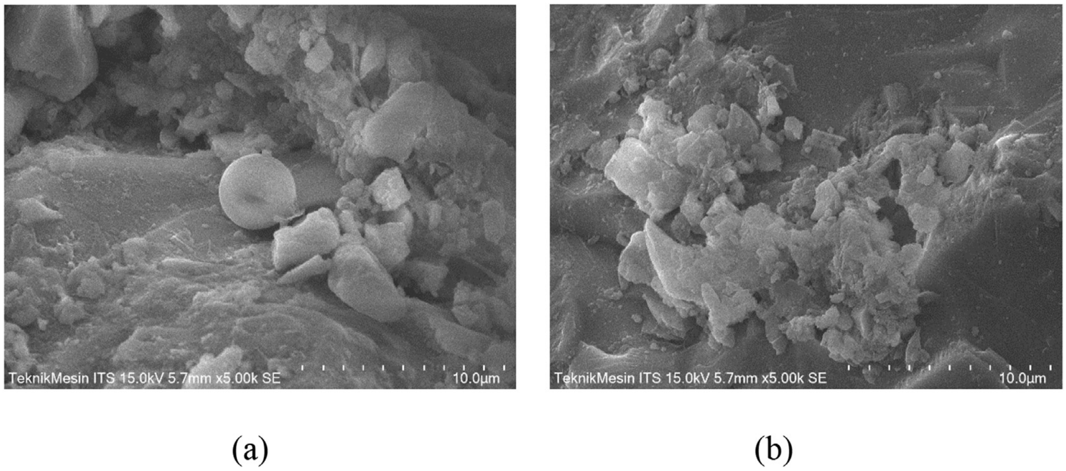


Figure 5. Results of SEM–EDX test on slow sand filter with 0.2 m/h filtration rate (a) and slow sand filter with 0.4 m/h filtration rate (b).

Schmutzdecke is consists of deposited synthesized materials from trapped microorganisms in sand grain (Hendricks et al., 1991). Most of the removal processes in slow sand filter occur in *schmutzdecke*, especially for biodegradable materials. Biodegradable particles are used by microorganisms, and they convert organic matter, such as water, carbon dioxide, nitrates, phosphate, and some minerals, into inorganic matter (Balen, 2018). These inorganic matter are the main challenges of nutrients removal. Therefore, some additional treatments, such as biomass bottom ash (BBA) for phosphate removal and autotrophic biofloc technology (ABFT) for nitrogen removal, are needed to improve the performance of slow sand filter. Alzeyadi et al. (2019) showed that BBA removes up to 90% of total phosphate, and slow sand filter removes up to 65% (Bali and Gueddari, 2019), where the efficiency number is constant with the work of Eturki et al. (2011) and Chennaoui et al. (2014). ABFT with microalgae (*Scenedesmus obliquus* and *Chlorella vulgaris*) and fish (Nile tilapia, *Oreochromis niloticus*) remove 50% of total ammonia nitrogen (Kim et al., 2019).

The normality test demonstrated that the removal efficiencies of slow sand filters with 0.2 and 0.4 m/h filtration rates were 0.962 and 0.813, respectively. The significance values indicated that the data of two reactors were normally distributed because they are larger than 0.05. The normality test result of two reactors was 0.068. These significance values signified that the data of two reactors were homogenous because they are larger than 0.05. The result of independent T-test showed that the significance value was 0.519, which was larger than 0.05, indicating no difference was found between the two reactors in removing coliforms.

3.3. Comparison between water quality treated using the combination of roughing filter and slow sand filter and the quality standards

The water treated using the combination of two reactors was compared to the quality standards stipulated in the Regulation of the Ministry of Health of the Republic of Indonesia Number 492/Menkes/Per/IV/2010 on the Quality Standards of Drinking Water. The comparison results are presented in Table 3.

The data presented in Table 3 indicate that the water treated using HRF–SSF reactor do not meet the quality standards. Therefore, the combination of two reactors are ineffective to treat Amprong River water to become raw water source for drinking water. Low coliform removal can be affected by the quality of raw water, size of media, thickness of media, and the contact time between raw water and the media.

3.4. Characteristics of bacteria on the schmutzdecke layer of slow sand filter

Bacterial inoculation using pour plate technique on the *schmutzdecke* layer of two slow sand filters resulted in 18 bacterial isolates. Their macroscopic characteristics were analyzed and found that they had small, moderate, and large colony sizes. The average bacterial colonies found in the *schmutzdecke* layer were small, with the smallest size of 0.14 cm. The number of small bacteria was nine isolates. The number of moderate-sized bacteria was six isolates with the range between 1.20 and 1.81 cm. The number of large bacteria was three, with the largest size of

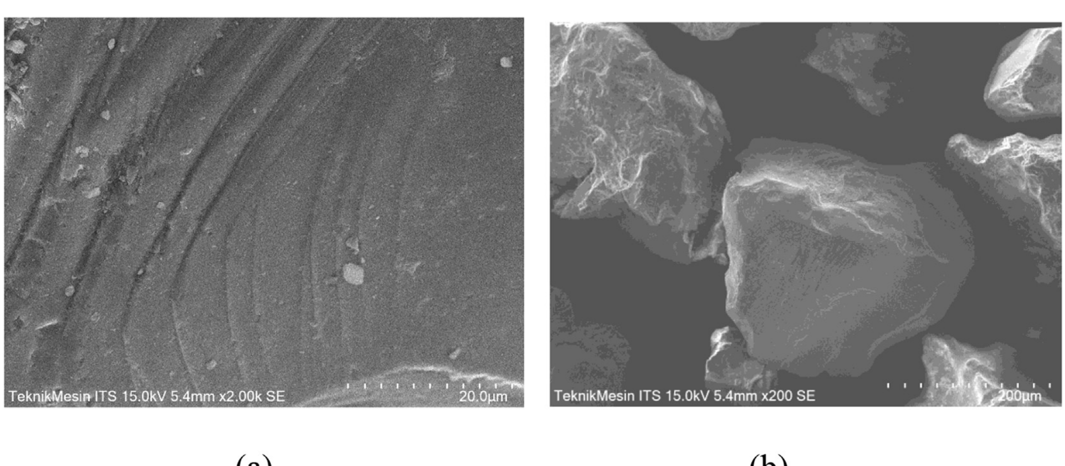


Figure 6. Result of SEM–EDX test on controlling sand media (a) and details of SEM– EDX sand grain (b).

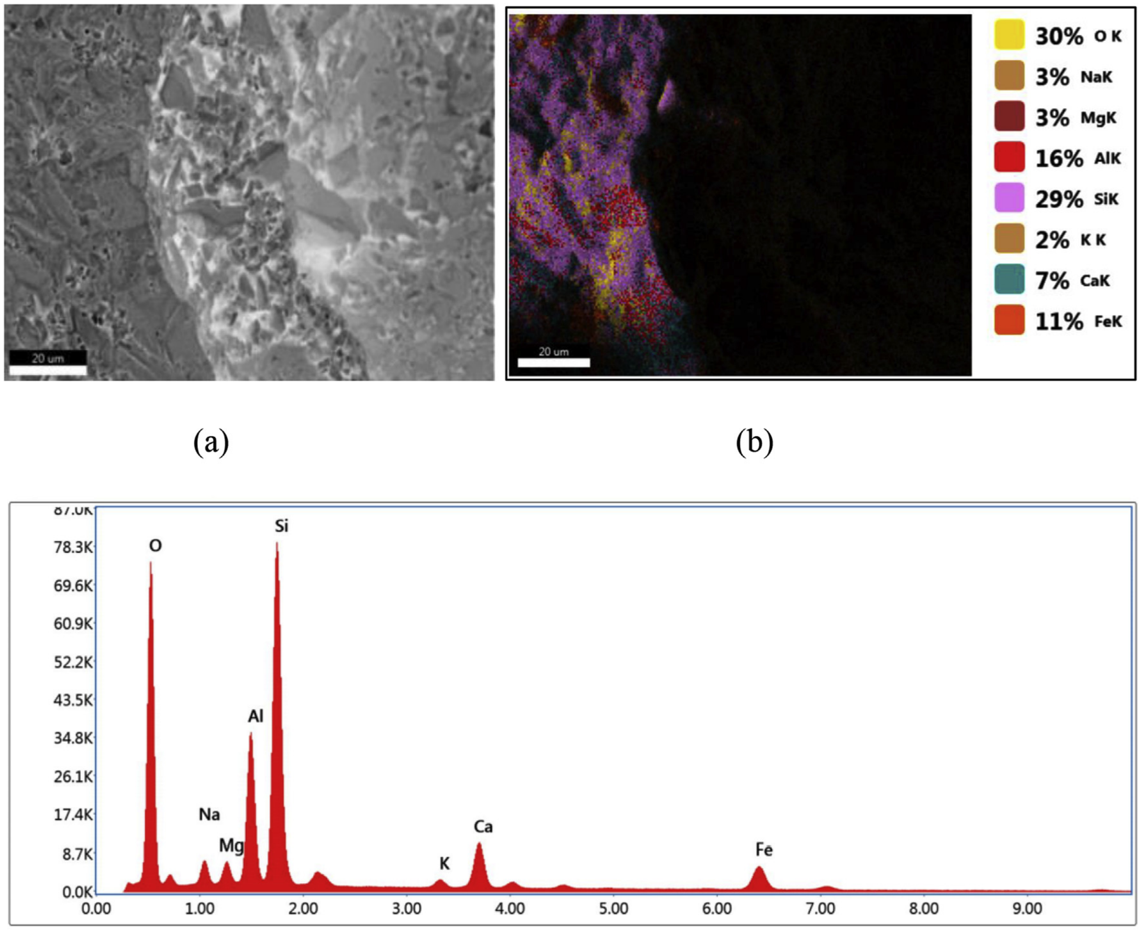


Figure 7. EDX results of sand media in slow (a), the mineral composition of sand media (b) and the spectrum results of sand filter media (c).

2.21 cm. Most bacteria were pigmented (colored colonies) and had white consistency that was opaque. The shapes of bacterial colonies varied, such as rhizoid (root-like shape), circular (straight-edged), irregular (curvy-edged), and filamentous (thread-like and spreading). Fourteen bacteria found on the *schmutzdecke* layer were circular.

Most bacterial colonies had entire edge or extremely wide edge. Other edges of the colonies included filiform (grows with resembling threads and a straight edge), undulate (has wave-like curves), lobate (has clear curves), and curled. The last characteristic of bacteria observed was the elevation form. Elevation is the cross-sectional shape of the colony. The bacteria had flat elevation on average although bacteria with raised elevation were found.

The 18 bacterial isolates were observed for their microscopic characteristics, and their cell sizes ranged from 1 μm to 3 μm. Twelve out of 18 bacterial isolates belonged to Gram-positive bacteria, whereas the remaining six were Gram-negative. Most of the bacterial cells on the *schmutzdecke* layer were basil-shaped.

3.5. SEM–EDX test results

SEM–EDX test was conducted on sand media in the last stage of slow sand filters with 0.2 and 0.4 m/h filtration rates and on the sand controlling media. SEM–EDX test was conducted to prove the formation of the *schmutzdecke* layer on the sand media. The results of SEM–EDX test are shown in Figure 5.

The results of SEM–EDX test on the sand media in the final stage of operating slow sand filters with 0.2 and 0.4 m/h filtration rates showed that the *schmutzdecke* layer was formed on the sand media in two reactors. The structure of the *schmutzdecke* layer consisted of mass deposit formed by several groups of microorganisms. The SEM–EDX test results were used to support the results of microscopic characteristic test, showing that basil- and coccus-shaped bacteria were found on the *schmutzdecke* layer. Joubert and Pillay (2008) indicated that the bacteria are found in *schmutzdecke,* and they are growing on the diatoms. Their shapes are fairly rod and coccus, indicating that they are well established in *schmutzdecke*.

This layer formed because of the accumulation of microorganisms and their activities, including extracellular and enzymatic products (Joubert and Pillay, 2008). The longer the filter operates, the more microorganisms will be contained in *schmutzdecke*. Therefore, the diversity of microorganisms increases with time. However, not all structures of microorganisms could be accurately identified on the basis of the micrograph.

The results of SEM–EDX test on the sand media in the last stage of operating slow sand filters with 0.2 and 0.4 m/h filtration rates were then compared with the controlling sand media. The results of SEM–EDX test on controlling sand media are presented in Figure 6, and the mineral composition in the sand media are presented in Figure 7.

Figure 7 shows that the composition of sand media consists of oxygen, silica, aluminum, ferrous, calcium, sodium, magnesium, and potassium. Oxygen (30%) has the highest percentage, and potassium (2%) has the lowest percentage. The mineral composition percentage spectrum is shown in Figure 7c.

4. Conclusion and recommendation

4.1. Conclusion

The concentration of total coliforms in Amprong River water treated using HRF was 72,700 colonies per 100 mL of sample, and its removal efficiency was 93.39%. The removal efficiency of vertical roughing filter was 93.07%, and the concentration of coliforms in the water treated by this filter was 76,200 colonies per 100 mL of sample. The concentration of biological parameters in Amprong River water treated using the combined units of HRF and slow sand filter with 0.2 m/h filtration rate was 4,386 colonies per 100 mL of sample, and its removal efficiency was 99.60%. The coliform concentration found in the water treated using HRF and slow sand filter with 0.4 m/h filtration rate was 6,219 colonies per 100 mL of sample. The filter unit achieved a removal efficiency of 99.43%. The *schmutzdecke* on slow sand filter was effective to remove the total coli. However, the quality of water did not meet the quality standards on the basis of the Regulation of the Ministry of Health of the Republic of Indonesia Number 492/Menkes/Per/IV/2010 on the Quality Standards of Drinking Water, especially on its biological parameter (total coliforms). The bacteria found in the *schmutzdecke* layer had several characteristics. Their sizes were small, moderate, and large. They were pigmented and had white consistency that was opaque. They had various shapes, including circular, rhizoid, irregular, and filamentous. The bacteria had entire, filiform, undulate, and curled edges and flat and raised elevations. They were Gram-positive and Gram-negative bacteria with basil-, coccus-, and cocoid-shaped cells.

Declarations

Author contribution statement

Nurina Fitriani: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Putri Eka Ardiyanti: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Wahid Dian Budiyanto: Analyzed and interpreted the data; Wrote the paper.

Dwi Ratri Mitha Isnadina: Conceived and designed the experiments; Performed the experiments.

Ni'matuzahroh, Eko Prasetyo Kuncoro & Radin Maya Saphira Radin Mohamed: Conceived and designed the experiments; Analyzed and interpreted the data.

Febri Eko Wahyudianto: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by Universitas Airlangga through the scheme of Mandat research funding No. 321/UN3.14/LT/2019.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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