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Research article

Performance of geotextile-based slow sand filter media in removing total coli for drinking water treatment using system dynamics modelling

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ABSTRACT

In a slow sand filter, a biological layer consisting of alluvial mud and various types of microorganisms grows and attaches to the sand media and forms a matrix called *schmutzdecke*. Changes to several factors, including the quality of raw water, filtration speed, and the addition of media, affect the performance of the slow sand filter unit in producing treated water. Geotextiles can be equipped to improve the performance of a slow sand filter in removing pollutants. The selection of several factors that affect slow sand filter performance can be used as a starting point for the engineering system to determine the best pattern of performance behavior. This approach was carried out by looking at the dynamic behavior patterns of slow sand filter system performance in treating raw water. This research has not yet been conducted extensively. The dynamic behavior pattern approach to the performance of the slow sand filter unit was used to obtain the behavior model for the *schmutzdecke* layer on the filter. The system dynamic approach focused on treatment scenarios that can determine the behavior of the slow sand filter system. Several factors were assessed, including temperature, turbidity, nutrient concentration, algal concentration, bacteria and dissolved oxygen. Model simulation results show that the comparison of C: N: P values affected the performance of the *schmutzdecke* layer in removing total coli. The slow sand filter unit was capable of producing treated water with a total amount of coli equal to 0 on the C: N: P values of 85: 5.59: 1.25, respectively, and a 9 cm geotextile thickness.

1. Introduction

River water, which is generally used raw as drinking water, has complex characteristics, because its elements have undergone several processes of transport and transformation. These processes result in changes of quality over time (Maharani et al., 2008). Rainy seasons and dry seasons also affect the quality and quantity of raw water. During the rainy season, river water generally has high turbidity, but other pollutants such as nitrate and phosphate are relatively low. Differences in pollutant concentrations, such as turbidity, total nitrogen (N), and total phosphorus (P), can affect the performance of the *schmutzdecke* layer during treatment using a slow sand filter. The composition of microorganisms in the *schmutzdecke* changes in accordance with the input and environmental conditions, as it is formed by specific groups of microorganisms (Joubert and Pillay, 2008; Ni'matuzahroh et al., 2020). The performance of the *schmutzdecke* layer in treating raw water needs to be preserved to maintain the quality of slow sand filter performance.

The addition of geotextile media consisting of fibers in the form of hydrophobic polymers has been effective in improving the performance of slow sand filters in removing pollutants (Rizki et al., 2013). Fibers in geotextiles can be a surface for the attachment of microorganisms, so that a matrix formed as slime fills the spaces between the geotextile fibers. Raw water that flows continuously causes an increase in decomposition products, resulting in the formation of a thick layer of biofilm. If this

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accumulation is continuous, then there will be clogging in the pores of the sand media. The thickening of the biofilm layer on the media causes a decrease in available surface area for the mass transfer of substrate or oxygen into the biofilm (Tangahu et al., 2019; Yaman, 2003).

Khumalasari and Hadi (2010) and Hendrayani et al. (2014) strengthened previous evidence that a slow sand filter unit is not capable of removing up to 100% of coli bacteria in raw water from Surabaya City river. In system thinking methodology, systems dynamic approach problems by capturing not only one main part, but by looking at all related elements in a holistic analysis. To identify the dynamic behavior pattern of the slow sand filter system, this study analyzes several treatment scenarios for the slow sand filter system model. The constituent and supporting components (such as sand media, raw water, and *schmutzdecke* layers), and the variables that affect system behavior (such as turbidity, algal concentration, dissolved oxygen concentration, filter media depth, sunlight, duration of acclimatization, and filtration speed) in a slow sand filter system, interact with one another through a causal loop. The novelty of this research is the use of geotextiles in the slow sand filter unit, and system dynamic modeling for the unit.

There has been limited research into system dynamic modeling, and even fewer studies involving slow sand filters with geotextile membranes. This research considers the performance of slow sand filter units with the addition of geotextile membrane using a system dynamic model. The results shed light on pollutant removal from water using slow sand filter units and may benefit institutions dealing with water treatment plants, especially in Indonesia.

2. Materials and methods

2.1. Study area and problem encountered

The Surabaya River is located in Surabaya City, Indonesia. The river is a source of raw water for two water treatment plants (WTPs) in Surabaya City. It is downstream of the Brantas River, and residential and industrial activities occur along the river. The pollutant load contained in the river is thus large, and fluctuates every day. At present, Surabaya WTP treats wastewater using physical and chemical processes that consist of three stages: sedimentation, coagulation and flocculation, and filtration including disinfection. The processed water from this WTP does not meet drinking water quality standards, especially for biological parameters.

2.2. Sample collection and experimental set-up

This study used raw water taken from the Ngagel 1 WTP, which originates from the Surabaya River. The water entering the roughing filter inlet unit comes from the pre-sedimentation unit outlet at Ngagel 1 WTP. Water entering treatment through the slow sand filter comes from the roughing filter unit outlet. The slow sand filter was equipped with geotextile media placed on the sand media. An acclimation process was carried out for 30 days before the treatment. The water sample analysis was carried out at the Department of Environmental Engineering, ITS Surabaya. The turbidity concentration of water treated by slow sand filters ranged between 3.06 to 40.7 nephelometric turbidity units (NTU). According to Jakok (2009), the turbidity of raw water in slow sand filters should be less than 10 NTU. Dissolved oxygen (DO) concentrations ranged from 4.7 mg/L to 6.6 mg/L. The total coli inlet bacteria were between 1×10^9 and 2.9×10^9 CFU/mL. The ratio of carbon, nitrogen, and phosphorus values in raw water was 37.5: 0.2: 1. Several studies have shown that the optimum C: N: P ratio in the biodegradation process is 100: 10: 1 (Lemos et al., 2013).

2.3. Model and formulation

The system dynamic modeling began with identification of the existing system using a slow sand filter. Identification was carried out by dividing the system into several subsystem models. Each subsystem in the model has variables that interact with one another and affect one another. The relationship between the model variables was illustrated in a causal diagram, where the causal relationship has a positive effect and a negative effect. The relationship between variables in the slow sand filter system formed a loop. Figure 1 shows the causal loop in the performance of the slow sand filter unit.

The modelled parameters were total coli, turbidity, nutrients (N and P), and dissolved oxygen. Cause and effect diagrams were created to determine the relationships of each variable, so that the relationship and the extent of its effect can be understood. A causal relationship between variables can be obtained by analyzing the changes in total coli effluent, which is affected by microorganisms in the *schmutzdecke* layer, the geotextile layer, and total coli input. Microorganisms in the *schmutzdecke* layer are also affected by total coli, C, N, and P nutrients, geotextile, and temperature. The loop also illustrates the relationship between geotextile and effluent turbidity, and total coli effluent, where a thicker geotextile will reduce the level of turbidity effluent and total coli effluent.

The general design of the formulation and the causal loop can be used as a basis for the formation of a system dynamics model structure. Stock, flow, and converter inputs are included in the structure of the model. Table 1 shows the input and output formulation of the dynamic behavior models pattern of slow sand filter performance.

The sample mathematical equations used in the modelling simulation for each subsystem are listed below:

Total coli in stock (t) = Total coli (t−dt) + (Total coli changes−Total coli effluent) dt (1)

Total coli in inflows = [(Round (Total coli + Total coli in raw water) × (Total coli rate changes)] (2)

C concentration in the system = C concentration in raw water − *Demand* C by Total coli (C concentration required by total coli in the *schmutzdecke*) (3)

Microorganisms in the *schmutzdecke* in stock = number of microorganisms in the *schmutzdecke* (t−dt) + (changes in the number of microorganisms in the *schmutzdecke*) dt (4)

Changes in the number of microorganisms in the *schmutzdecke* = microorganisms in the *schmutzdecke* × rate of change in microorganisms in the *schmutzdecke* (5)

The main model of a slow sand filter system consists of three variables, which are assumed to have the most influence on the performance of a slow sand filter. The purpose of creating the main model is to simplify the relationship between stock and flow that exists in each subsystem model. The main model is therefore expected to illustrate this

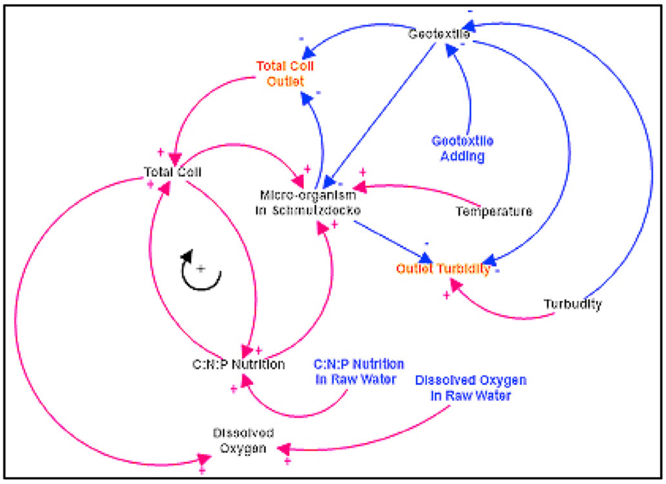

Figure 1. Causal loop diagram of slow sand filter.

Table 1. System dynamic input and output formulation for total coli subsystem model in slow sand filter system.

Building block	Remarks of *building block*	Unit of building *block*
Stock	Total Coli	CFU/ml
	Schmutzdecke	CFU/ml
Flow	Total Coli rate changes	CFU/ml
	Total Coli effluent	CFU/ml
Converter	C concentration in raw water	(mg/l)
	N concentration in raw water	(mg/l)
	P concentration in raw water	(mg/l)
	C concentration in system	(mg/l)
	N concentration in system	(mg/l)
	P concentration in system	(mg/l)
	Total Coli per dissolved oxygen	(mg/l/total coli)
	Demand of dissolved oxygen for total coli (the number of dissolved oxygen requirement per total coli)	(mg/l)
	The number of total coli in raw water	CFU/ml
	The number of N (percent)	%
	The number of P (percent)	%
	The number of C (percent)	%
	Demand C by Total Coli (C concentration required by Total Coli in *schmutzdecke*)	(mg/l)
	Demand N by Total Coli (N concentration required by Total Coli in *schmutzdecke*)	(mg/l)
	Demand P by Total Coli (P concentration required by Total Coli in *schmutzdecke*)	(mg/l)
	C concentration per Total Coli (The C concentration that required per Total coli)	(mg/l)
	N concentration per Total Coli (The N concentration that required per Total coli)	(mg/l)
	P concentration per Total Coli (The P concentration that required per Total coli)	(mg/l)

relationship in the slow sand filter unit system model. Figure 2 shows the main model of the slow sand filter system.

2.4. Subsystem model

The slow sand filter model consisted of three subsystems: total coli, turbidity, and *schmutzdecke*. Figure 3 shows the total coli model subsystem structure; the amount of C, N, and P; and oxygen concentration as variables that affect changes in total coli in the system.

Figure 3 explains the flow in the total coli model subsystem in the *schmutzdecke* layer system, where the values of the C, N, and P research results are included as the input variables of the C, N, and P values in the model. The value of N per total coli represents the amount of N needed per total coli, and the same representation follows for C and P per total

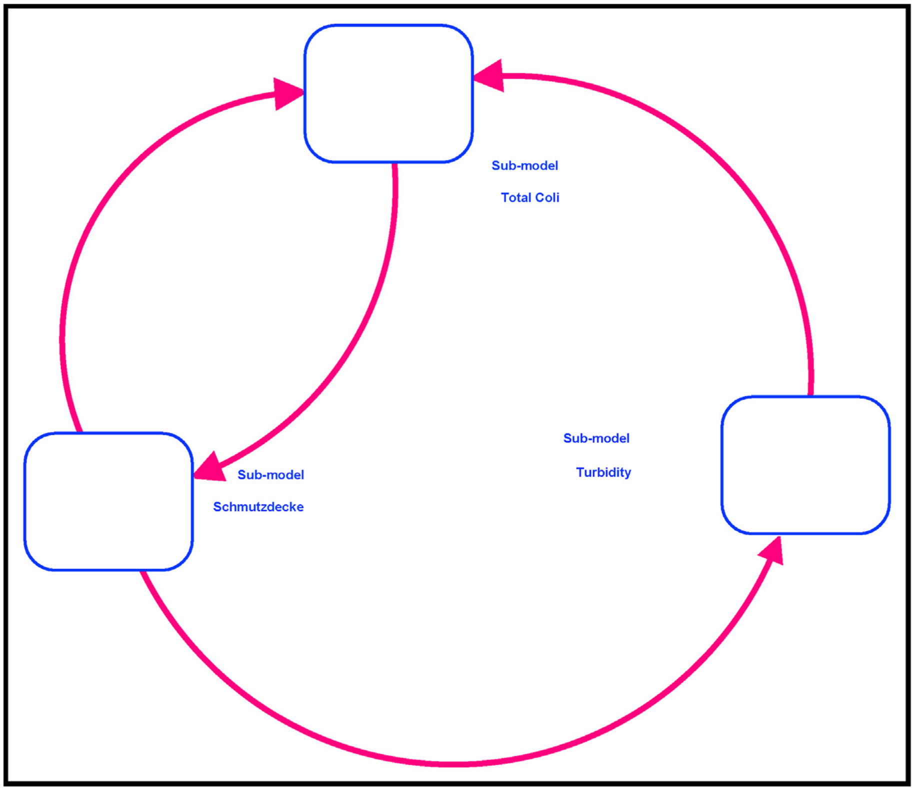

Figure 2. Main model of slow sand filter.

coli. Variable demand P by total coli is a description of the total amount of P needed by total coli at a given time. This subsystem model also illustrates the relationship between the total number of coli in the system and the amount of P demand or P demand required by the total coli for its activity and development. The same is true for the relationship between variable N demand by total coli and demand C by total coli. The P value variable in the system also means the remaining P content in the system after being reduced by the demand for P by the total coli.

The turbidity model subsystem was described in terms of the relationship between inlet turbidity and outlet turbidity, which is influenced by the *schmutzdecke* layer and geotextile material. The addition of a geotextile coating material to the slow sand filter processing unit can reduce the turbidity that enters the system (Rizki et al., 2013). In this subsystem model, the turbidity removal efficiency is affected by the thickness of the geotextile. Figure 4 illustrates the stock and flow from the turbidity model subsystem.

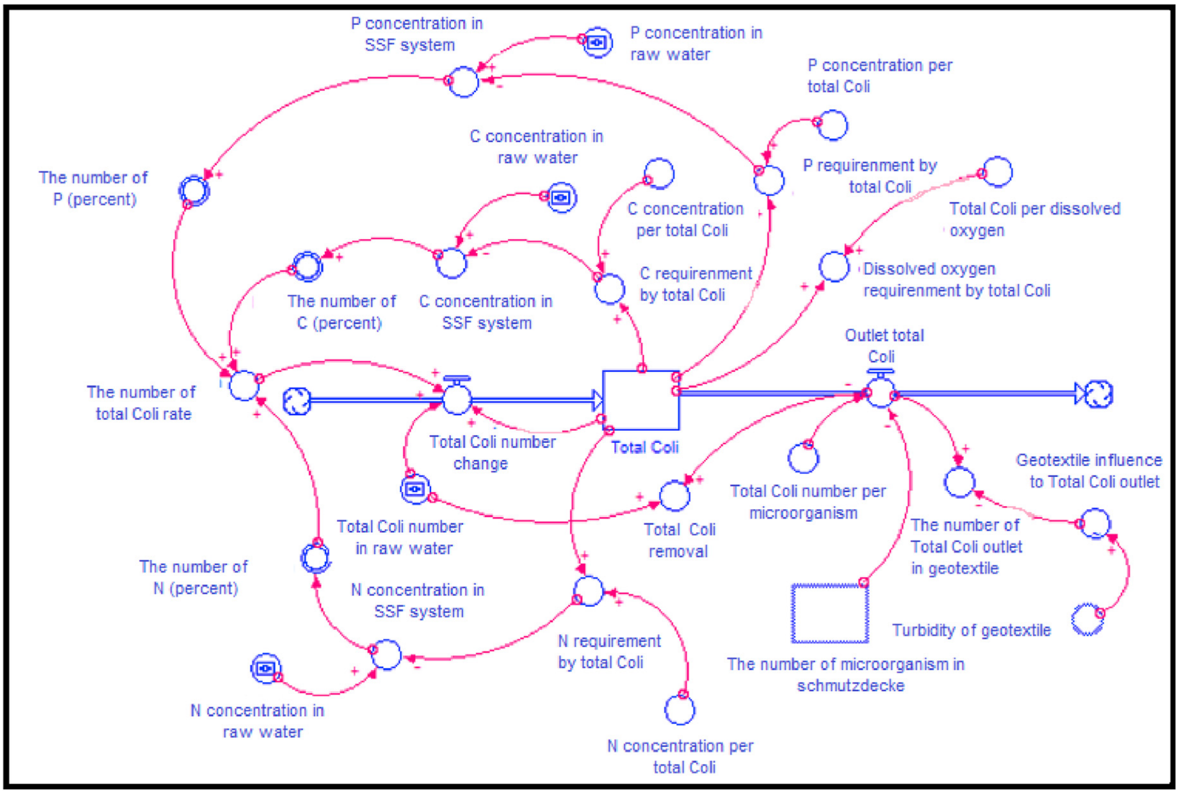

Figure 3. Stock and flow diagram for the total coli subsystem model.

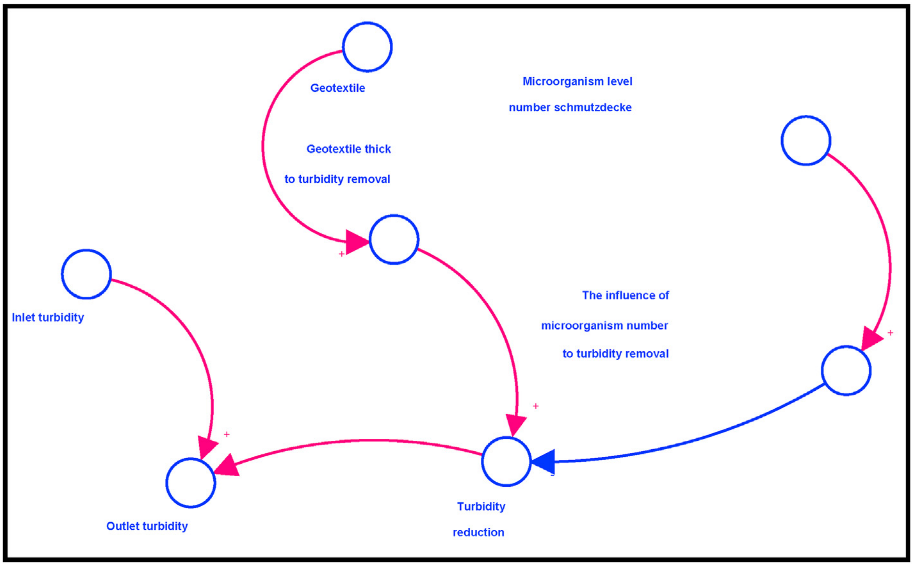

Figure 4. Stock and flow diagram for the turbidity subsystem model.

The subsystem structure of the *schmutzdecke* layer model was affected by conditions of changes in C, N, and P; dissolved oxygen; and temperature. The percentage change from each of the variables above is then related to changes or microorganisms in the *schmutzdecke* layer. The correlation between these variables results in an increase or decrease in the number of microorganisms in the *schmutzdecke* layer. The increasing percentage of variables results in an increase in the number of microorganisms; the rate of change in the number of microorganisms thus affects the change in microorganisms over time. The number of microorganisms in the *schmutzdecke* layer also increases. Figure 5 explains the *schmutzdecke* layer sub model in the system.

2.5. Validation model

The validation test conducted in this modeling study is the output model validation. This step is performed using a value from the output of the simulation model with the output of the actual slow sand filter system, which is in the form of analysis results obtained from laboratory experiments. The process used in this validation test uses two methods, the white box and black box methods. The white box method includes all variables and interrelationships between variables in the model obtained from experts in this study. The black box method compares the average value of actual data with the average value of simulation data.

The validation test in the black box method can be performed using a model structure test, model parameter test, boundary adequacy test, or extreme conditions test. On the basis of these validation methods, the slow sand filter performance pattern model of the formulation and the unit was accepted by evaluators, and the model simulation results for all of the parameters are in accordance with actual logic. The model is therefore qualitatively valid. The final validation is a replication test or model behavior analysis. This test is carried out by comparing the behavior of the model with the actual system behavior. The model is valid if the error value obtained from the difference between the actual value and the value of the simulation model < 0.1. The equation used to find the average error between the two values is as follows:

$$E = |(S - A)/A| \tag{6}$$

The comparison of the average values from the research data (actual conditions) with the average values on the simulation model results showed that all variables are less than 0.1.

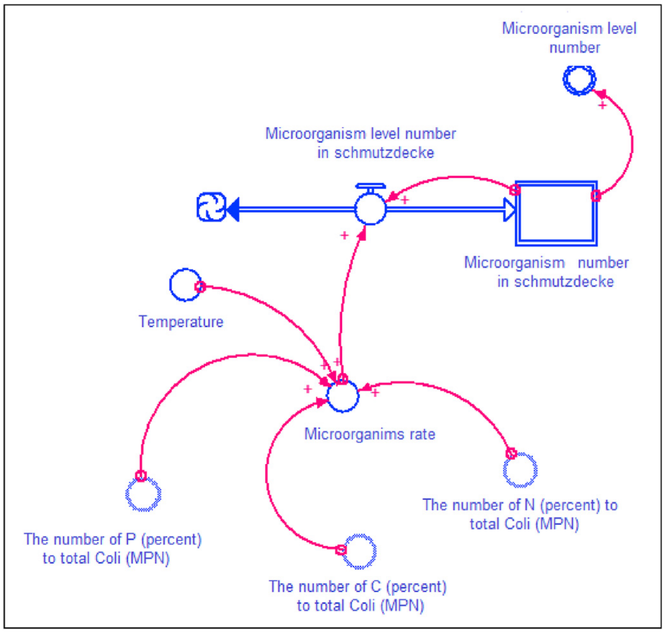

Figure 5. Stock and flow diagram for the *schmutzdecke* subsystem model.

3. Results and discussion

3.1. Total coli model

The total coli decrease percentage was obtained in the subsystem simulation of the total coli model from the performance of the *schmutzdecke* layer. Table 2 shows the model simulation results.

Table 2 shows that the total amount of coli in raw water is volatile every day, and ranges from 1,744 MPN/100 ml to 42,175 MPN/100 ml. The total amount of coli in the fluffed raw water affects the total amount of coli at the outlet according to the simulation model, however, the slow sand filter unit is able to reduce the total amount of coli in the raw water. The percentage of total coli removal in the slow sand filter unit was between 79.76% to 99.46%. This result was caused by the presence of the *schmutzdecke* layers that formed on the filter media, however, on the fifth day, the percentage of total coli removal was only 79.76%, because the *schmutzdecke* layer had not formed completely. As a result, the ability of the layer to remove total coli had not been maximized. On Days 6–14, the slow sand filter unit was able to eliminate up to 99.46% of the total coli in the slow sand filter. The large percentage of allowance is due to the various processes taking place in the *schmutzdecke* layer. The growth of microorganisms that form in the *schmutzdecke* layer, including the total coli in it, is also affected by the presence of C, N, and P. These three elements must be in the right ratio to achieve the optimal growth of microbes, especially bacteria. Studies show that the optimum C: N: P ratio in the biodegradation process is 100: 10: 1 (Lemos et al., 2013), while according to Redfield et al. (1963), the C: N: P ratio for bacteria should be 106: 16: 1. Other studies have shown that a ratio of 100: 5: 1 is the optimum condition for bacterial culture. In reality, raw water that enters the slow sand filter unit has C, N, and P concentration ratios that are below optimal conditions. Laboratory research shows that the average C: N: P ratio is 37.5: 0.2: 1. The amount of C in this case is represented by the COD concentration which has fluctuating concentrations every day, whereas the P concentration is higher than the N concentration. Table 3 presents the concentrations of C, N, and P in raw water.

Fluctuating ratios of C: N: P in raw water prevent the microorganisms that form the *schmutzdecke* layer from reaching optimum conditions for the degradation process and for the bacterial culture process. This means that the total coli removal process in the slow sand filter does not reach 100%. The slow sand filter unit is capable of removing coli bacteria, because according to Huisman and Wood (1974), microorganisms in the *schmutzdecke* layer in slow sand filters produce a substance that functions as a chemical or biological toxin for coli bacteria. This condition is achieved if the quantity of nutrients needed by microorganisms including C, N, and P is met.

A low C: N ratio (high N content) will increase emissions from N as ammonium, which can inhibit bacterial proliferation. A high C: N ratio (low N content) will slow down the degradation process because nitrogen will be a growth-rate limiting factor (Imron et al., 2020). The C: N ratio depends on the contaminants that need to be degraded, bacteria, and the type of N used.

3.2. Turbidity model

This turbidity sub simulation model obtained the percentage of turbidity values successfully reduced by the slow sand filter unit. Turbidity values were modelled at the inlet and outlet in the simulation, along with the percentage of turbidity parameter removal. The decrease in turbidity was due to physical and biological processes in the slow sand filter (Ainsworth, 2007). This physical process is in the form of mechanical straining, which is done by mechanical filtering using grains of sand media. Particles that cause turbidity and escape in this process settle on the surface of sand media which has smaller grain size than particles that cause turbidity. The slow sand filter unit is equipped with geotextile media that can helps maintain the optimal performance of the slow sand filter unit. The slime matrix formed can fill spaces between geotextile

Table 2. Total number of coli in the inlet and outlet of the slow sand filter.

Total Coli in raw water (MPN/100ml)	Total Coli outlet (MPN/100ml)	The percentage of Total Coli removal (%)
42,175.00	383.00	99.09
13,427.00	163.00	98.79
9,160.00	107.00	98.83
13,581.00	212.00	98.44
1,744.00	353.00	79.76
6,849.00	48.00	99.30
10,173.00	279.00	97.26
6,319.00	34.00	99.46
13,114.00	456.00	96.52
30,661.00	1,165.00	96.20
6,699.00	107.00	98.40
6,645.00	99.00	98.51
14,542.00	827.00	94.31
30,224.00	1,792.00	94.07
Average percentage		96.35

fibers. Continuous water supply forms thicker layers of biofilm, which clog media pores and increase decomposition products. The biofilm layer becomes thicker, thus decreasing the surface area available for the mass transfer of substrate or oxygen into the biofilm (Yaman, 2003). Biofilms consist of microorganisms and particulates that bind together, and an extracellular layer results from the activity of microorganisms, which form a matrix (Perry and Staley, 1997). The amount of biomass increases, causing a reduction in the contact area of raw water and biofilm, which in turn reduces mass transfer and processing efficiency. Geotextiles made from PET or PP are hydrophobic, and so suspended particles carried in raw water can trap microorganisms, where the matrix formed between geotextile fibers is affected by variations in pore size (Yaman, 2003). Geotextiles can function as a filter when the turbidity of raw water is high. They can also function as a medium for growing bacteria when turbidity is normal. The presence of this layer can improve the performance of slow sand filters in removing pollutants such as N and P in raw water (Hamidah and Trihadiningrum, 2013; Rizki et al., 2013).

3.3. Schmutzdecke model

This value is demonstrated in the *schmutzdecke* sub model simulation by the number of microorganisms on the basis of their growth rate. The *schmutzdecke* layer consists of alluvial sludge, organic waste, bacteria, algae, and biologically active compounds, which all eliminate organic materials and change the synthetic organic compounds of pathogenic bacteria, parasitic protozoa, and suspended solids (Schuler et al., 1991; Aslan and Cakici, 2007; Huisman and Wood, 1974). The *schmutzdecke* layer consists of microorganisms such as bacteria, diatoms, and zooplankton (Joubert and Pillay, 2008). This layer is generally formed within a few hours or up to weeks, depending on the type of bacteria and microorganisms that survive (Joubert and Pillay, 2008; Prakash et al., 2003). Microorganisms undergo several phases during the growth stage, from the breeding phase to the death phase. The growth stage of microorganisms consists of four phases: the initial phase, the logarithmic or exponential phase, the stationary phase, and the death phase (Trihadiningrum, 1995). Table 4 shows the growth of microorganisms in the *schmutzdecke* layer in the simulation model.

Table 4 shows that the rate of change in microorganisms fluctuates every day, because microorganisms are affected by the nutrients present in raw water. Laboratory results show that the average C: N: P ratio is 37.5: 0.2: 1. The amount of C, in this case represented by the COD concentration, has fluctuating concentrations every day; whereas the P concentration is higher than the N concentration. The presence of C, N, and P will affect the growth rate of microorganisms (Imron et al., 2019) in the *schmutzdecke* layer.

Table 3. Concentrations of carbon, nitrogen, and phosphorus in raw water.

Day-	Inlet (mg/L)		
	COD	N	P
1	90.14	0.424	2.151
2	103.70	0.412	1.809
3	82.63	0.397	1.650
4	107.18	0.411	2.263
5	115.46	0.408	2.034
6	67.37	0.391	1.834
7	42.11	0.382	1.804
8	50.53	0.388	1.706
9	82.05	0.376	1.737
10	41.03	0.398	2.427
11	104.10	0.390	2.652
12	84.21	0.379	2.197
13	42.11	0.373	2.100
14	50.53	0.364	1.936

Table 4. Growth rate and the number of microorganisms in the *schmutzdecke* layer.

Rate of microorganism number	Changes in microorganisms in the *schmutzdecke*	Microorganisms in the *schmutzdecke* (CFU/ml)
0.03	7,450,240.00	280,000,000.00
0.23	66,841,772.49	287,450,240.00
0.04	14,641,004.05	354,292,012.49
0.12	43,134,424.82	368,933,016.54
0.20	81,571,285.39	412,067,441.36
0.51	251,219,418.77	493,638,726.75
0.11	78,580,948.95	744,858,145.52
0.01	4,289,625.68	823,439,094.46
0.23	190,208,845.29	827,728,720.14
0.27	277,639,264.71	1,017,937,565.43
0	(2,825,289.26)	1,295,576,830.15
0.03	32,780,724.86	1,292,751,540.00
0.19	254,037,427.42	1,325,532,265.75
0.24	377,621,719.25	1,579,569,693,17

3.4. Scenario model

This scenario model subchapter reports on variable conditioning performed to obtain the best condition of the slow sand filter system, which is 0 coli effluent. The scenario designs used refer to the previous model. This scenario is based on conditions that allow it to be controlled in a slow sand filter unit system. The scenario used involves conditioning the values of C, N, and P and geotextile thickness. The selection of this scenario was based on variables that significantly affect the system, and can be implemented. Three scenarios have been used in previous studies: changes in dissolved oxygen concentration, geotextile thickness, and changes in C, N, P. The scenario of changes in dissolved oxygen concentration did not significantly affect the simulation results, and therefore, only two scenarios are used in this study, the thickness of the geotextile, and changes in the values of C, N, and P.

3.4.1. The C, N, and P scenario

The scenario of changes in the range of C, N, and P values in the model is based on a study of the literature and the values of C, N, and P in laboratory experiments. The range of C values used as a scenario in the model is 40–100 mg/L, the range of N values is 0.3–10 mg/L, and the range of P values is 0–5 mg/L. These ranges are based on research conducted by Lemos et al. (2013), in which the optimum C: N: P ratio in the biodegradation process is 100: 10: 1; whereas according to Redfield et al. (1963), the ideal ratio is 106: 16: 1. Other studies state that the optimum C: N: P ratio for bacterial culture is 100: 5: 1, and a ratio of 44: 9: 1 for oligotrophic conditions (Chrzanowski et al., 1996). Kusumawardani et al. (2014) recommended that a C: N: P ratio of 22.73: 0.132: 1 should be used to obtain 0 coli effluent in simulation model results. Figure 6 is a graph of the trial and error simulation model values of C, N, and P and the effect of the percentage change in the values of C, N, and P on the system.

As seen in Figure 6, the trial and error simulation model values of C, N, and P indicate that the best condition for the slow sand filter unit system was achieved on Days 8–12. During this period, the total amount of coli effluent was equal to 0. This condition was achieved when the values of C, N, and P were 85 mg/L, 5.59 mg/L, and 1.25 mg/L, respectively. The C, N and P values in the scenarios increases the percentage of slow sand filter removal from total coli from 96.35% to 98.46%. A slow sand filter is able to remove the pollutants contained in raw water through physical, chemical, and biological processes. The physical process takes place from the beginning of the slow sand filter operation. The pore diameter of the smallest media is 20 μm; and so, the medium cannot filter colloidal particles which have a diameter of ≤ 1 μm or bacteria up to 15 μm in length (Huisman and Wood, 1974). At this stage, the physical process dominates, and thus the reduction in turbidity has reached more than 85% (Fitriani and Hadi, 2010; Rizki and Karnaningroem, 2014; Fitriani et al., 2014). In addition to physical processes, there are also slow sand filter chemical process, namely the electrostatic

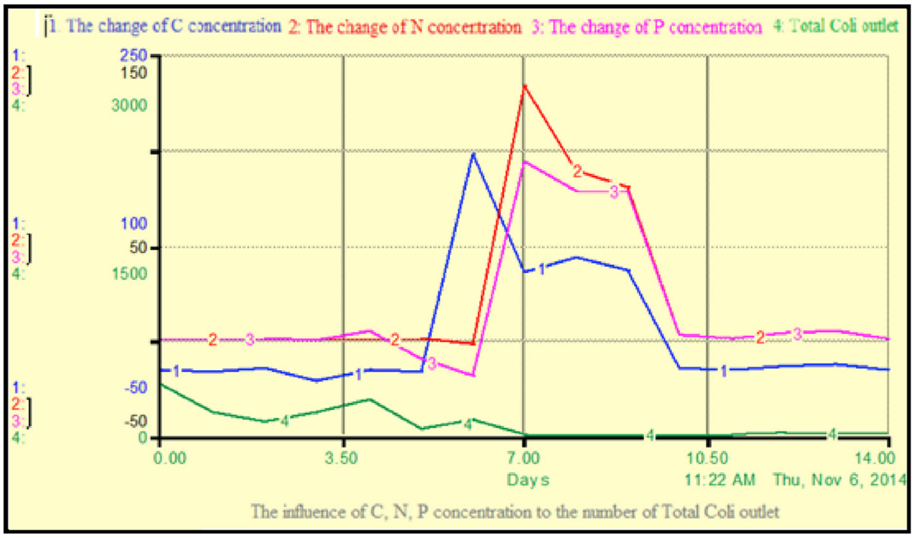

Figure 6. Behavior of C, N, and P in the system.

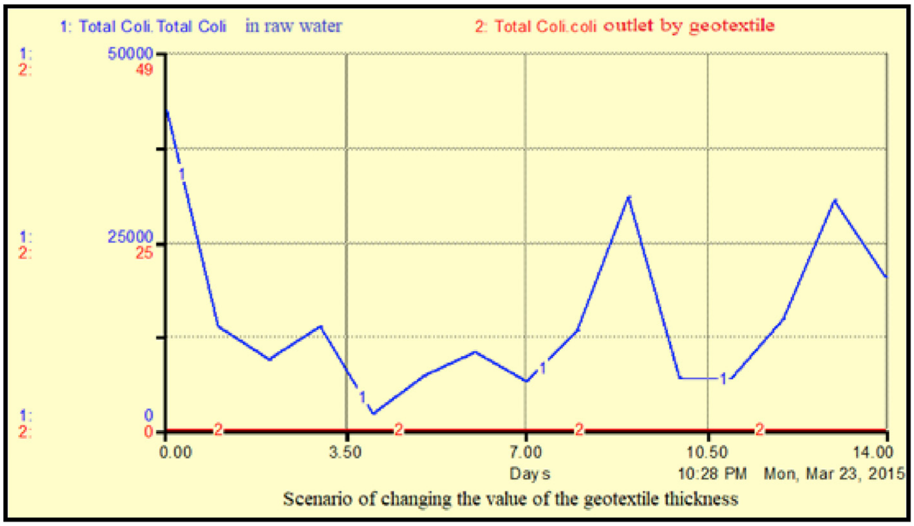

Figure 7. The effect of the behavior layer in the system.

force. Sand media generally have a negative charge, whereas colloidal particles such as carbonate crystals and aluminum hydroxide, have a positive charge. This difference in charge results in an attractive force between the sand media and colloidal particles. As a result, particles attach to the entire surface of the media. This attachment causes other colloidal particles that have a negative charge, such as bacteria, to stick on the sand media, which has been positively charged (Huisman and Wood, 1974). This process is one of the reasons the total amount of coli effluent in the simulation results of the model did not reach 0 on Days 1–6. The grains of sand were alsonot fully positively charged.

A biological process also occurs in a slow sand filter. This process dominates the *schmutzdecke* layer formed in the slow sand filter. This layer has a complex architecture, which is rich in the mucopolysaccharides produced by in situ microorganisms and dead algae. This layer, with a thickness of ± 2 cm, is composed of concentrated biological material that serves as a place to grow and develop bacteria on top of the sand (Huisman and Wood, 1974). This layer also consists of bacteria, diatoms, and zooplankton (Joubert and Pillay, 2008). Cooking periods generally range from a few hours to weeks, depending on the type of bacteria that forms them (Prakash et al., 2003; and Joubert and Pillay, 2008). The diversity of microorganisms in the *schmutzdecke* also increases with the length of the operating filter (Joubert and Pillay, 2008). The existence of a *schmutzdecke* layer greatly helps slow down sand filter performance, because these layers produce high population densities that enable them to use nutrients efficiently, and become more resistant to environmental changes (Lazarova and Manem, 1995; Prakash et al., 2003; Purwanti et al., 2017). The growth of biofilms attached to the media in the *schmutzdecke* layer causes several activities between microorganisms, including biodegradation activity against pollutants. According to Prakash et al. (2003), the growth of biofilms attached to the media had higher biodegradation activity against pollutants than the growth of suspended biofilms. Model simulation results on the 7th to 12th days show the best condition of the system. This observation is indicated by the amount of coli in the effluent equal to 0. After the 12th day, the amount of coli in the effluent increases again. This increase is possible because at that time, the *schmutzdecke* layer formed is not yet "mature". Microorganisms in the *schmutzdecke* layer in the slow sand filter produce a substance that functions as a chemical or biological poison for coli bacteria. When the filter reaches its best condition, the formed *schmutzdecke* layer is "ripe." This condition is achieved if the quantity of nutrients needed by microorganisms including C, N, and P is met. Organic compounds carried by raw water serve as food for the microorganisms that exist in the *schmutzdecke* layer. The oxidation of organic matter by microorganisms produces energy for metabolic processes (dissimilation), and other organic material is converted into new cells for growth (assimilation). Products produced from the dissimilation process are reused by microorganisms that are underneath the sand media. Organic matter that can be decomposed will be converted by bacteria into water, carbon dioxide, and inorganic salts, such as sulfate, nitrate, and phosphate, which will carry water into the effluent.

3.4.2. *The geotextile scenario*

In this study, the thickness of the geotextile used was 6 cm. The simulation model in this second scenario, in addition to using a C: N: P nutrient change scenario, also uses a geotextile thickness change scenario. The thickness of the geotextile used in this second scenario is between 0–9 cm. The next treatment involves trial and error for each number in the range. Figure 7 presents the results of the trial and error simulation of the geotextile thickness number model with respect to the total number of coli parameters.

In the trial and error for the geotextile thickness, the best condition is achieved for the slow sand filter system when the thickness is 9 cm. At this point, the percentage of total coli removal also increased from 98.46% in the scenario of changing the value of C, N, and P to 100%. This scenario shows that the presence of a geotextile layer can speed up the system in removing total coli. Figure 7 shows that the system was able to remove up to 100% of coli from the first day. Kusuma and Hadi (2018) have also demonstrated that the use of geotextiles can achieve 100% coli removal.

Similar to the *schmutzdecke* layer, there are physical and biological processes in the geotextile layer. The physical process that occurs is the process of filtering particles carried by raw water that cause turbidity, known as a blocking process. Fibers in the geotextile function as filter media. Geotextiles also affect the biological processes, where different forms of growing media also affect the shape of the resulting biofilm layer. Biofilm matrices are formed irregularly in the *schmutzdecke* layer, and tend to fill cavities between sand media. Biofilm matrices on geotextile media are formed in cavities between geotextile fibers are attached to these fibers, and are flat like a plate (Yaman, 2003). The biofilms that form consist of microorganisms and particulates that bind together and form a matrix of extracellular results (Perry and Staley, 1997).

The first model scenario is the change in nutritional values of C, N, and P, and the second scenario is the change in geotextile thickness. The first and second scenarios are unified and sequential. As a result, they cannot be reversed, because the concentrations of C, N, and P have been contained in raw water, and this scenario cannot be separated from the model. The first model scenario is different from the scenario of changes in geotextile thickness, where this layer is a model variable that can be separated and the scenario for the model can also be separated from the model. The slow sand filter system model, one of which is formed from the ratio of the value of C, N, P, is also due to the existing conditions of raw water. If the model scenario for the ratio of C, N, P values is zero, then the model will be far from the real system.

4. Conclusions

Engineering models in a slow sand filter system as a WTP are capable of producing a model of the behavior of the system. The use of a system dynamic methodology in this study determined the factors that have a significant effect on the pattern of system behavior in the unit and certain treatments needed in determining the best behavior pattern of the system. The simulation results of the slow sand filter system model show that the system achieves its best behavior when the C, N, and P values are 85 mg/L; 5.59 mg/L; and 1.25 mg/L, respectively, and when the geotextile thickness is 9 cm. This finding is indicated by the ability of the system to produce 100% total coli allowance during the unit operation. The engineering model with a geotextile layer scenario shows that this layer is able to accelerate total coli removal in the slow sand filter system.

Declarations

Author contribution statement

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

Maritha Nilam Kusuma: Performed the experiments; Analyzed and interpreted the data.

Joni Hermana & Budi Santoso Wirjodirdjo: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ni'matuzahroh, Setyo Budi Kurniawan, Siti Rozaimah Sheikh Abdullah & Radin Maya Saphira Radin Mohamed: Analyzed and interpreted the data; Wrote the paper.

Wahyono Hadi: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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