COMBINED EFFECT OF SLOW SAND FILTER AND ROUGHING FILTER WHILE ADDING A COAGULANT CHEMICAL FOR IMPROVING TURBIDITY REMOVAL

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ABSTRACT

The prominent drinking water treatment processes practised to eliminate turbidity from surface waters are coagulation, sedimentation and rapid sand filtration. However, the possibility of removing turbidity using the combination of Roughing Filter (RF) as pre-treatment and Slow Sand Filter (SSF) was not extensively studied in the case of high turbidity occurrence in the surface water. This study aimed to evaluate the performance of the combination of RF (as the pre-treatment) and SSF in terms of turbidity removal in surface water when pre-adding PolyAluminium Chloride (PACl) as a coagulant chemical. One per cent of PACl is prepared and dosed at the rate of 20 mg/L with raw water into the water intake chamber before it reaches the RF. The raw and treated water samples were collected at six-hour intervals. The raw water samples of which turbidity level is more than 80 NTU were considered and analysed from 63 nos of trials. The turbidity level of raw water and treated water was observed in the range of 80.4 - 185 NTU and 0.3 - 5.5 NTU respectively. The turbidity removal from RF alone and SSF alone was 87.4% and 86.4% respectively. However, the average turbidity removal in the combined technique was 99.2% and the turbidity of treated water was observed to be well below the SLS 614; 2013 acceptable limit of 2 NTU in 97% of the treated samples. This methodology shall enable the proper function of the treatment plant, during the turbidity level of less than 185 NTU in raw water, by complying with SLS 614-2013.

KEYWORDS: *Drinking water, Poly-aluminium chloride, Surface water treatment, Turbidity removal.*

1. INTRODUCTION

There are many natural resources on the planet and water is one of them. 71% of the earth's surface is surrounded by water. Approximately only 3% of this water is freshwater. However, only a small portion of water, (about 0.3%), is consumed by humans. Water is a basic need of all living forms. In addition, water is required as a raw material for many industries. Hence, the contribution of water to a country's economic development is significant. Though water is a basic human need, over 785 million people do not have access to basic drinking water facilities. Globally, it is estimated that over 2,000 million people consume drinking water from water sources contaminated with faecal matter. Further, it is forecasted that half of the world's population will be in water stress regions in another five years according to World Health Organization (2017).The water treatment process plays a vital role in supplying uninterrupted, safe, and clean water to the consumers. There are many levels of water treatment available and practised at present such as household-level, community level and domestic level. There are various conventional water treatment techniques namely slow sand filtration, roughing filtration, and rapid sand filtration.

Part of the Kilinochchi district in the Northern Province of Sri Lanka is being supplied with potable water treated by the Kilinochchi Water Treatment Plant (WTP), which has the capacity of 3,800 m^3/ day. As illustrated in Figure 1, the treatment process of the WTP include pumping water from the intake to roughing filter, then to the aerator and to Slow Sand Filter (SSF) and finally to clear water ground sump. The water source is surface water, extracted from Dry Aru which is fed by Iranamadu tank. As per the WTP operation manual, the raw water turbidity level must be less than 80 NTU before it enters the RF for proper operation (NJS Consultants Co., 2019) and effluent turbidity level must be less than 30 NTU before entering into the slow sand filter to prevent clogging of the filter media of SSF (NWSDB, 1989).

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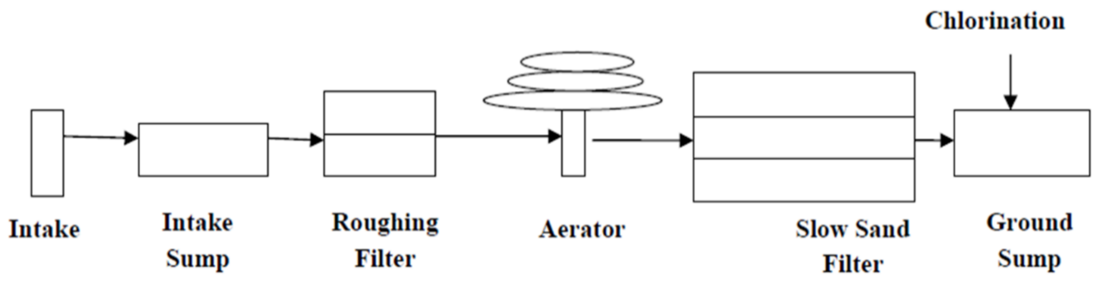


Figure 1: Existing Water Treatment Process

However, the turbidity of raw water increases from 100 to 350 NTU during the rainy season, which interrupts the plant's efficient operations. The prominent drinking water treatment process practised to eliminate turbidity from surface water, especially during high turbidity occurrence is coagulation, sedimentation and rapid sand filtration. However, this methodology cannot be adopted in the Kilinochchi WTP, since it does not include comprise coagulation, sedimentation and rapid sand filtration techniques. Nevertheless, a practical solution is vital to treat water during the rainy season for high turbidity levels in raw water by using the existing water treatment plant facilities.

The quality of drinking water is judged by various parameters and turbidity is one of them (Agrawal et al., 2020). The extent to which suspended solids in water scattered or absorbed by the light is termed as turbidity. The clarity of water can also be discussed in terms of the turbidity level. The transparency or clarity of the water is affected by the suspended solids and presence of colour in water. There are many reasons for the suspended solid existence in water such as decayed vegetation, fungi, slit, and algae, which lead to high turbidity in water. Nevertheless, the relationship between suspended solids and turbidity in quantitative terms is not yet proven. The sunlight penetration is disturbed by high turbidity, which affects the process of photosynthesis.

There are a few pre-treatment techniques to treat raw water to prevent rapid clogging and frequent cleaning of the WTP. However, the roughing filtration process is one of the most reliable techniques used currently for this purpose. Reducing the turbidity load on the slow sand filter can be obtained by the proper functioning of a roughing filter. Either down flow or up flow are the operating flow patterns in the vertical-flow roughing filters. Vertical-flow roughing filters are designed to have complete submergence of the filter media, often with the gravel, with various particle sizes in layers (Nkwonta and Ochieng, 2009).

The performance of the horizontal Roughening Filter (RF) was studied by constructing a pilot horizontal RF in Northern region of Ghana and turbidity removal efficiency was recorded as 46% (Nkwonta and Ochieng, 2009). The turbidity removal efficiency using roughing filter in several previous studies are tabulated in Table 1.

Table 1: RF Turbidity removal in previous studies

Reference	Removal Efficiency	Influent Turbidity Value
Jayalath (1994)	60%	23 FTU
Dastanaie (2007)	63.4%	5.5 NTU
Ochieng and Otieno (2004)	84%	125 NTU
Mahvi (2004)	90%	200-400 NTU

A slow sand filter (SSF) was originally established by John Gibb, in Scotland (Ellis, 1987). The main advantages of SSF over the other filters are less energy requirement and cost-effectiveness, ability to function well with minimal or no dependency on work force and chemicals. SSF is one of the sustainable water treatment processes. In general, the physical, biological and chemical processes function together in the removal of contaminants and other impurities from the raw water. Many developed countries such as Japan, Scotland and Netherlands are using SSF as a solution to treat water (Anggraini and Fuchs, 2019).

Many SSF pilot studies have been done by the researchers using plastic and concrete materials for the frame and different graded gravel and sand as filter media in layers in the past. There are several factors mainly, characteristics of water source, temperature, hydraulic retention time, surface area, filtration rate, and filter media size which influence the design and the performance of the SSF. However, the grain size of the filter media and depth control the efficiency of the water treatment (Anderson et al., 2009).

Different types of filter operations such as slow filter operation and fast filter operation were used with fine and coarse sand filter media by Ellis during his study in 1985. 60-65% removal of suspended solids and 70-75% removal of BOD_5 was recorded in the study when using slow filter media (Ellis, 1987). Many findings suggest that SSF method can be used to treat different types of water and wastewater. In addition, drinking and wastewater treatment efficiencies of SSF have been about 99% for removal of turbidity, pathogens and suspended solids. Up to 99% is recorded as the efficiency of wastewater and drinking water SSF (Haarhoff and Cleasby, 1991).

It is a vital requirement to remove the organic matter in the potable water treatment due to its stress on the treatment process and potential to form carcinogenic disinfection by-products, and the impacts on plant efficiency and aesthetics (Wegelin, 1996). The coagulation process is used in most water treatment plants (WTP) as the most accepted and cost-effective pre-treatment process for the removal of organic matter and suspended solids in water. The purpose of coagulation is to destabilize the particles' charges. Coagulants with charges opposite to the suspended solids are added to the water to neutralize the negative charges on dispersed non-settable solids.

Once the charge is neutralized, the small-suspended particles are capable of sticking together.

During the coagulation process, the surface charge properties of solids are changed to enhance the agglomeration and/or enmeshment of tiny particles into larger flocs by a few Aluminium-based compounds or polymers, namely: aluminium chloride, aluminium sulphate (alum), and poly aluminium chloride (PACl). The coagulation process is very effective for removing turbidity when PACl is added (Zhao *et al.*, 2011). Previous studies indicate that the efficiency of PACl as the coagulant is more than that of alum, mainly due to its higher overall positive charge (Zouboulis et al., 2008).

As per Hashimoto et al, (2019), a technique consisting RF as pre-treatment and SSF in WTPs was introduced, designed and constructed to treat surface water from rivers. Further, their effective performance was reported. A few electrical and mechanical equipment were used because of the simplicity of the treatment system. There are many advantages in having treatment techniques with the combination of RF and SSF in terms of easier construction, simple design less maintenance and economic benefits in operation and maintenance.

The turbidity removal efficiency using the combination of up flow roughing filter and slow sand filtration through a pilot plant was studied in Zambia and turbidity removal efficiency was recorded in the range of 32-93% (Nkwonta and Ochieng, 2009) .

As per the WTP operation manual, the raw water turbidity level must be less than 80 NTU before it enters the RF for proper operation (NJS Consultants Co., 2019) and turbidity level must be less than 30 NTU before entering into the slow sand filter to prevent clogging of the filter media of SSF (NWSDB, 1989). However, the turbidity of raw water increases to 100-350 NTU during the rainy season, which results in interrupting the plant's efficient operations.

The prominent drinking water treatment processes used to eliminate turbidity from surface water, especially during high turbidity occurrences are coagulation, sedimentation and rapid sand filtration. However, this methodology could not be adopted in the existing Kilinochchi WTP, since it does not have the required physical facilities for coagulation, sedimentation and rapid sand filtration. Nevertheless, a practical solution is vital to treat water during the rainy season for high turbidity by using the existing water treatment plant infrastructure.

The improved treatment technique consists of roughing filter followed by the SSF to treat drinking water, in the case of high turbidity occurrence in the surface water. However, the advantages of the use of pre-oxidation chemicals have not been considered in this study.

Hence, the objective of the present study is to evaluate the performance of roughing filter and SSF in terms of turbidity removal from raw water when adding coagulant chemicals, by utilizing the existing WTP infrastructure.

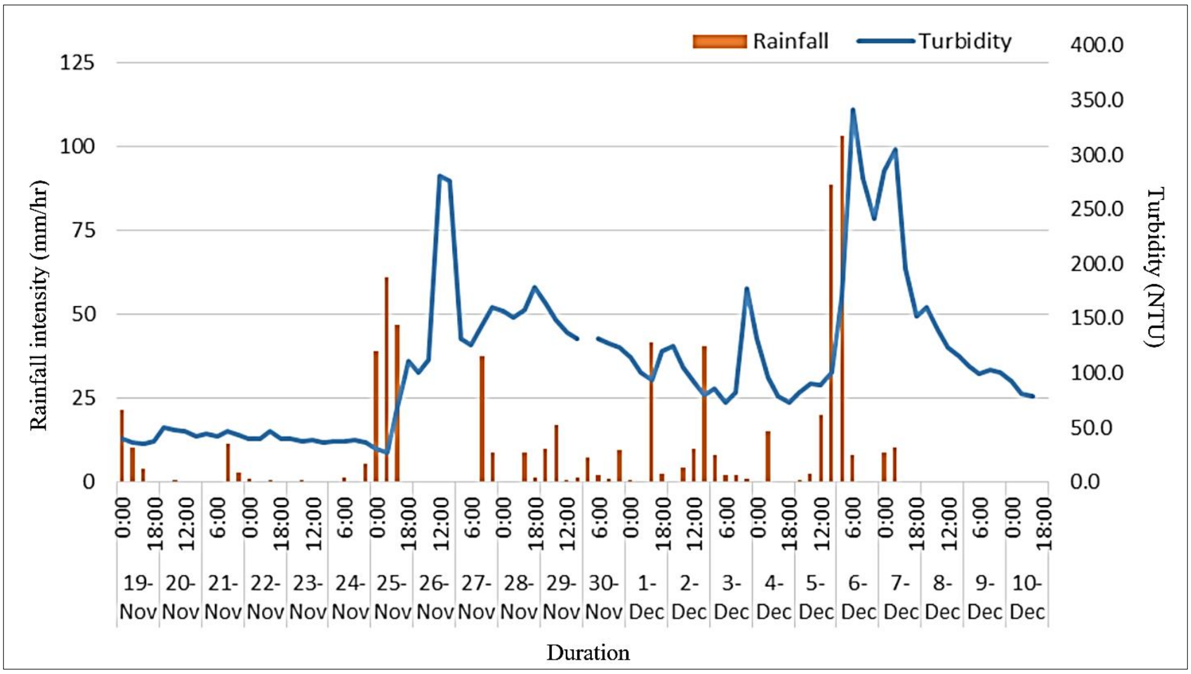


Figure 2: Rainfall vs raw water turbidity level

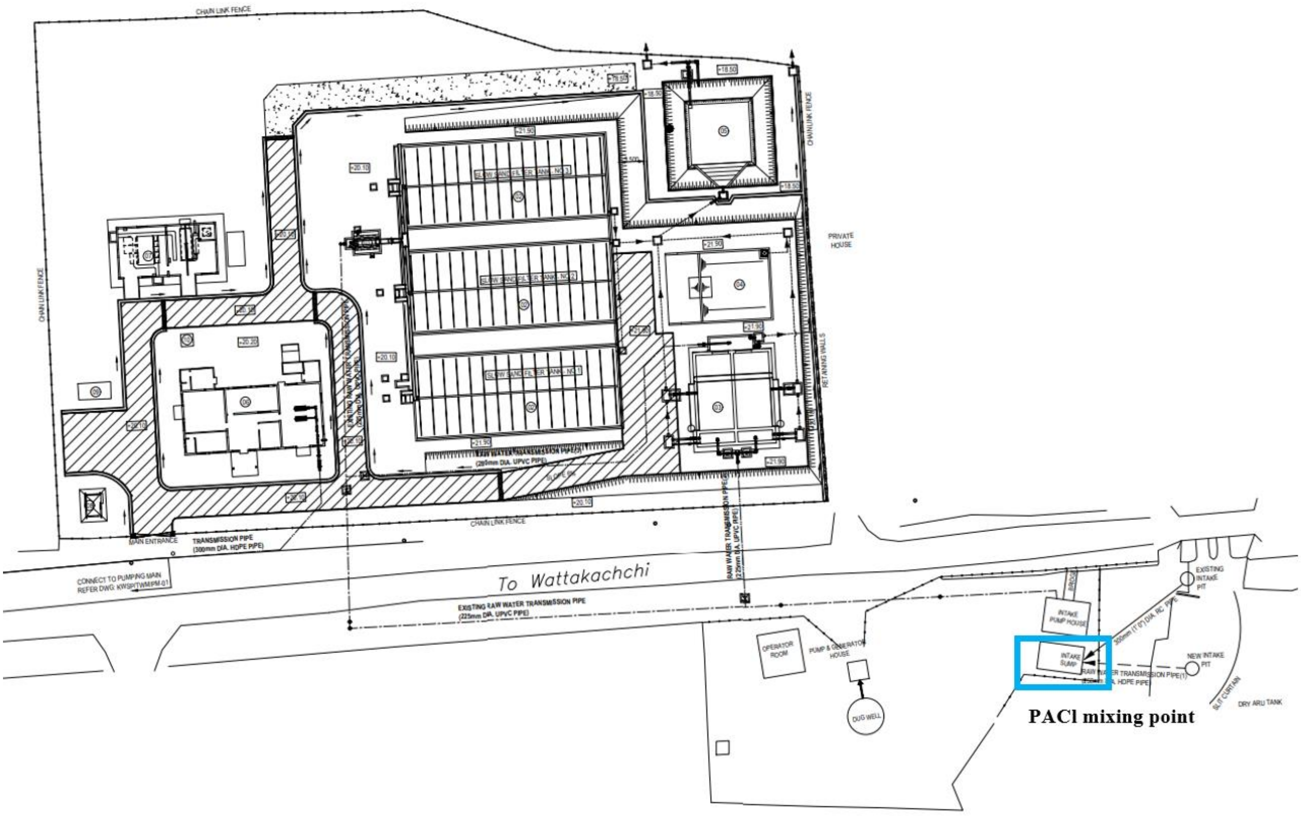


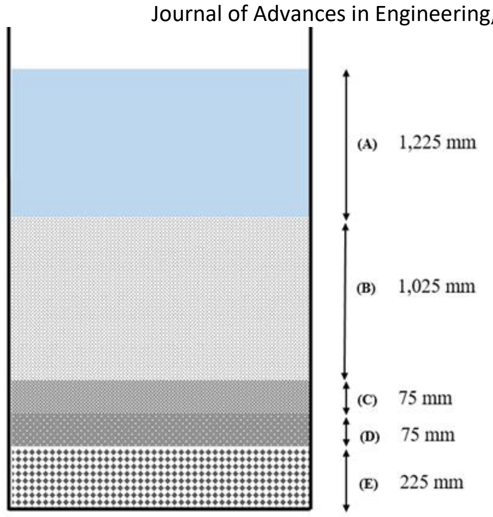
Figure 3: WTP layout and PACl mixing

2. METHODOLOGY

Part of the Kilinochchi district in the Northern Province of Sri Lanka is being supplied with potable water treated by the Kilinochchi water treatment plant, which has a capacity of 3,800 m^3 /day. The raw water source is surface water, extracted from Dry Aru which is fed by Iranamadu tank. The raw water turbidity level is influenced by the rainfall in the catchment area. The rainfall amount and the measured raw water turbidity is shown in Figure 2. Turbidity shows an upward trend soon after the increase of rainfall. Soon after a rainfall of 60 mm/hr on 25th November 2020, a turbidity level of 111 NTU was recorded. The following day, turbidity increased to 280 NTU. Turbidity level of 350 NTU was recorded after the rainfall of 90 mm/hr on 6th December 2020.

No rainfall occurred between December 8 and 12, and the turbidity levels decreased to 55 NTU. It was found by analysing the existing data of rainfall and turbidity, that there is a relationship of rainfall to turbidity level of raw water in Dry Aru, from which the water is extracted. The turbidity level of raw water generally satisfies above condition in the dry season. However, according to the records the turbidity of raw water increases to 100-350 NTU during the rainy season, which reduces the efficiency of the water treatment plant operations. The treatment process of the plant includes pumping water from the intake, roughing filter, the aerator, SSF and finally clear water ground sump. However, a new methodology was adapted and tested to the existing treatment process during the rainy season where higher levels of turbidity arises.

As per the WTP operation manual, the raw water turbidity level must be less than 80 NTU before it enters the RF for proper operation (NJS Consultants Co., 2019) and water turbidity must be less than 30 NTU before entering into the slow sand filter to prevent clogging of the filter media of SSF (NWSDB, 1989). Therefore, the methodology used was, adding Poly Aluminium Chloride (PACl) as the coagulant chemical to activate the coagulation process from which the suspended solid particle can efficiently form clogs within a short period and be removed through the RF, to reduce the additional pollutant loads on the SSF.



Where;

(A) Water column over the filter media
(B) Filter media sand layer
(C) Filter gravel layer 1
(D) Filter gravel layer 2
(E) Filter gravel layer 3

Figure 4: Cross-section of SSF

Figure 5: Fine aggregates and gravels as filter media in SSF

A jar test was conducted to choose the most suitable chemical coagulant from alum and poly-aluminium chloride and to estimate minimum coagulant dose required to achieve certain water quality goals. Based on the findings from the jar test, (1%) of PACl was prepared and dosed at the rate of 20mg/L. The prepared solution was mixed with raw water into the water intake chamber before it reaches the RF as shown in Figure 1. In addition, the inlet structure of RF was modified to improve the rapid mixing of PACl with raw water.

Gravel with various particle sizes of 4-8 mm, 8-12 mm, and 12-16 mm with a layer thickness of 1,000 mm each was used as filter medium of the RF. The filter media of the SSF was placed as a 1025 mm thick layer of fine sand with a uniform coefficient of 1.78 and effective size of 0.32mm along with gravel with various particle sizes of 5-9 mm, 5-16 mm, and 9-62 mm with a layer thickness of 75, 75, and 225 mm respectively as shown in Figure 4 (not to scale). The water depth over the filter media was 1,225 mm approximately.

The appearance of coarse and fine aggregates which have been placed in SSF as the filter media is shown in Figure 5. The turbidity level of raw water sample and the effluent sample from RF and SSF were measured at every six-hour intervals. The turbidity is measured and analysed for 63 numbers of trials. Turbidity was measured by a 2100Q turbidity meter at the site laboratory.

3. RESULTS AND DISCUSSION

Turbidity removal by roughing filter is presented in Figure 6. The turbidity level in the raw water sample and treated water by the roughing filter when adding PACl as the coagulant agent were compared. The samples whose raw water turbidity exceeds the limit of 80 NTU were taken into consideration for the analysis. The raw water, before sending it to SSF, generally needs to have less than 30 NTU of turbidity to prevent the clogging of slow sand filter media.

The result illustrates that turbidity is removed significantly by the proposed methodology. The turbidity of water treated by the roughing filter was observed to be well below the threshold limit of 30 NTU in 93% of the treated water samples collected at the roughing filter outlet. The turbidity of raw water for 63 samples during the testing period varied in the range of 80.4 - 185 NTU, whereas turbidity of the treated water from the roughing filter was observed to be between 1.49 - 44.6 NTU.

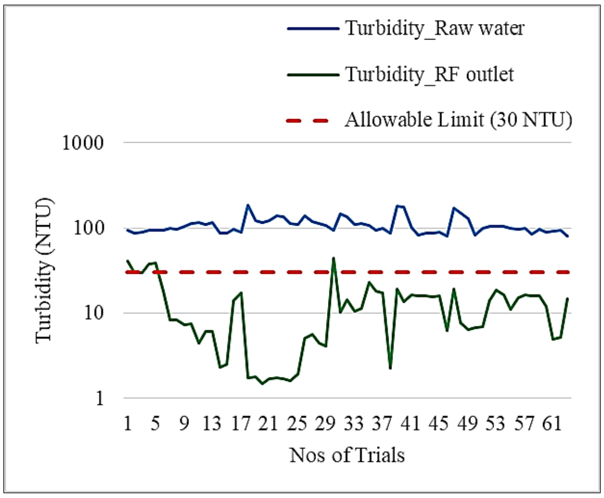


Figure 6: Comparison of turbidity in raw water and effluent in RF

The turbidity removal efficiency was calculated by using Equation 1.

Figure 7 indicates that 56 out of 63 samples (88.9%) were observed to be above 80% efficiency in removing turbidity by RF.

$$Effciency(\%) = \frac{(Influent\ concentartion - effluent\ concentartion)}{Influent\ concentartion} * 100$$

Equation 01

As per the previous studies, by using the roughing filter prototype model, the turbidity removal efficiency of the roughing filter was recorded as 82% in the presence of PACL. Consequently, the current study records the average turbidity removal efficiency of roughing filters as 87.4%.

In addition, the turbidity removal efficiency in roughing filters was tested through a few previous studies (Jayalath *et al.*, 1994; Jafari Dastanaie *et al.*, 2007 ;Ochieng *et al.*, 2004; Mahvi *et al.*, 2004). The turbidity removal efficiency of RF was recorded as 75%, 60%, 63.4%, 84%, and 90% respectively. Turbidity removal efficiency observed in the present study is above the findings of most of the previous studies.

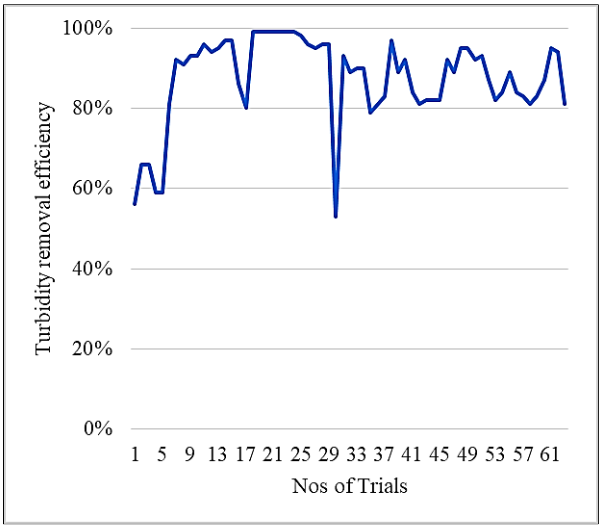


Figure 7: Turbidity removal efficiency in RF

Turbidity removal by the slow sand filters for the influent and treated water is shown in Figure 8.

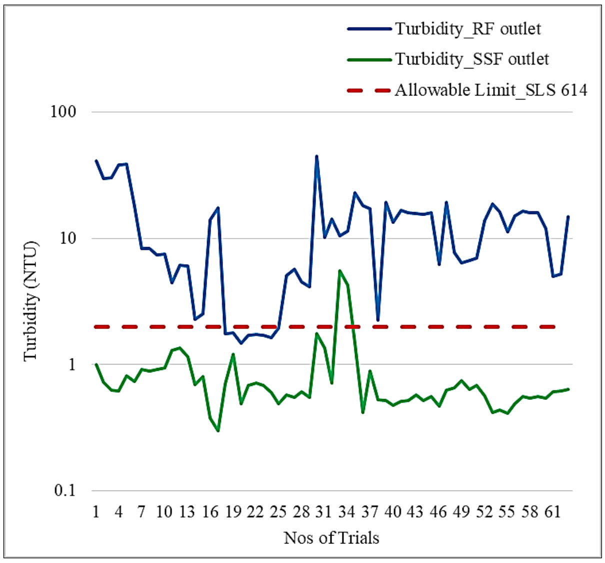


Figure 8: Comparison of turbidity in influent and treated water in SSF

The results illustrate that the turbidity is removed significantly by the proposed methodology of pre-addition of PACl with raw water and with the pre-treatment of RF and filtration by SSF. The turbidity of treated water from SSF was observed to be well below the SLS 614;2013 (SLSI, 2013) acceptable limit of 2 NTU in 97% of the treated samples when applying this method. Turbidity of influent to SSF during the testing period varied in the range of 1.49- 44.6 NTU, whereas turbidity of the filtered water from SSF was observed between 0.3-5.5 NTU.

Figure 9 indicates that 48 out of 63 samples observed to be above 80% efficiency in removing the turbidity. In a previous study, the same methodology was assessed through a prototype model of the same water treatment plant and turbidity removal efficiency was found to be 90% and it was increasing with the increasing turbidity of the inlet water to the SSF.

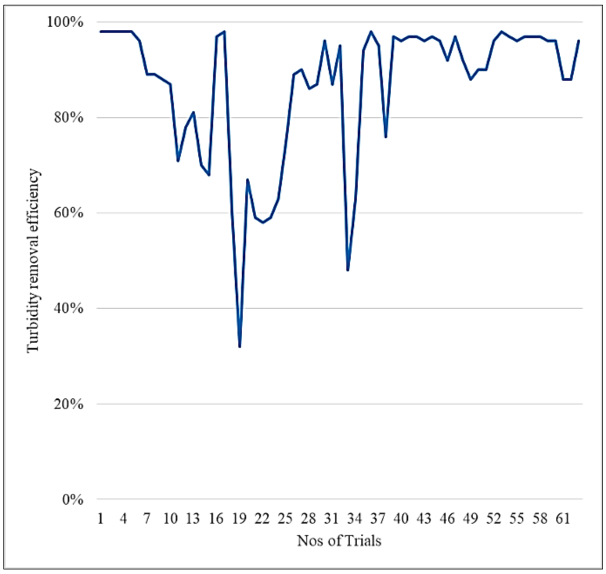


Figure 9 : Turbidity removal efficiency in SSF

However, the present study records the average turbidity removal efficiency of SSF as 86.4%.

Further, there is a correlation observed between the time and turbidity removal efficiency, where the efficiency increases with the days of operation. In addition, it was recorded in a previous study that, a long operation of a water treatment plant increased the turbidity removal efficiency (Jenkins et al, 2011). In addition, it is also recorded that, drinking and wastewater treatment efficiencies of SSF have been about 99% for removal of turbidity, pathogens and suspended solids. Up to 99% is recorded as the efficiency of wastewater and drinking water SSF (Haarhoff and Cleasby, 1991).

The turbidity removal found in previous studies is higher than that of the present study. The reason would be that most of the turbid pollutants are significantly removed by the roughing filter. Nevertheless, the turbidity of treated water by SSF was observed to be well below the SLS 614;2013 (SLSI, 2013) acceptable limit of 2 NTU in 97% of the treated samples when applying this method.

The turbidity removal efficiency using the combination of up-flow roughing filter and slow sand filtration techniques through a pilot plant was studied in Zambia and turbidity removal efficiency was recorded in the range of 32-93% (Nkwonta and Ochieng, 2009). In contrast, the overall turbidly removal efficiency by the combination of RF and SSF by implementing this methodology under the present study is recorded as 99.2%. The overall turbidly removal efficiency is presented in Figure 10.

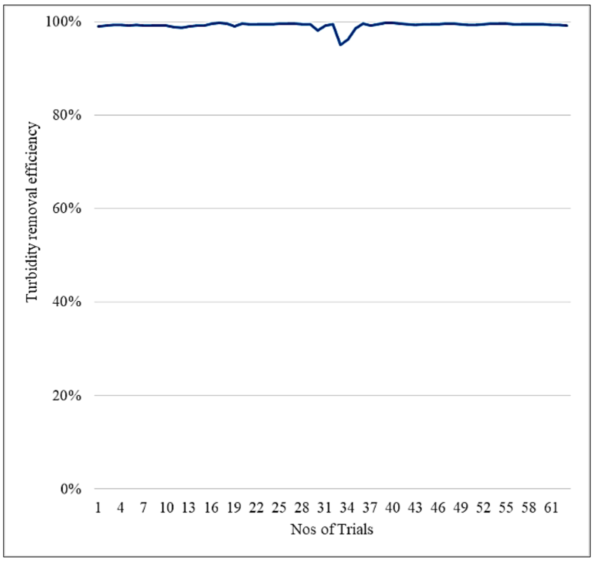


Figure 10: Turbidity removal efficiency in combined RF and SSF

The backwashing to clean the filter media is inevitable in any WTP. The backwashing of the roughing filter occurred once in 2-3 days for 3-4 hours in the event of high turbidity in raw water during this study. The reduction in the frequency of backwashing when adopting this methodology can be considered as a drawback in this study.

4. CONCLUSION

The research objective was to evaluate the performance of roughing filter and SSF in terms of turbidity removal from surface raw water by adding coagulant chemicals. The past year's records show that the WTP operation is interrupted when raw water turbidity is high, especially during the rainy season. The result illustrates that the turbidity is removed significantly by adopting the current methodology. It was observed that the treated turbidity level is well below the threshold limit of 2 NTU, specified in SLS 614; 2013 for drinking water, in most of the trials when adopting this method. Individual treatment efficiency of RF (as the pre-treatment) and SSF (as the final treatment) were at a satisfactory level while the combined turbidity removal efficiency was at exceptional level. This method is very efficient and can be applied for turbidity treatment for highly turbid surface water used in drinking water supply systems.

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