Water treatment efficiency of aerator and roughing filter in treating groundwater; A case study in Mullaitivu

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Abstract— *The paper describes an investigation into the efficiency of the water treatment process used in the Mullaitivu well field in Sri Lanka. The well field experiences significant groundwater extraction, approximately 1,440,000 liters per day, due to developments and resettlements in the area over the past decade. However, the groundwater quality does not meet the standards set in SLS 614;2013. The treatment process employed in the well field includes a fountain type aerator and vertical-flow roughing filters. The fountain type aerator has four drops with varying heights. The water then passes through four medial filter layers in the roughing filters, each with different particle sizes and layer thicknesses. To assess the effectiveness of the treatment process, water samples were collected at regular intervals of 6 hours during 72 hours continuous operatio. The samples were taken before and after aeration and after passing through the roughing filters. The selected water quality parameters tested in the study were turbidity, color, total iron, and manganese. The results showed that the treatment process using the aerator and roughing filters significantly removed color and total iron from the raw water. The removal efficiencies were found to be 84% for color and 88% for total iron. Additionally, the treated water's turbidity was well below the threshold limit of 2 NTU, the treated manganese level was below the limit of 0.1 mg/l, and the treated total iron level was below the limit of 0.3 mg/l specified in SLS 614;2013 for drinking water. Based on the findings, the paper recommends including pre-chlorination in the treatment process to enhance oxidation and increase the total iron and manganese removal efficiency. By doing so, the removal efficiency for turbidity and color will also be improved. Overall, the investigation suggests that the combination of the fountain type aerator and vertical-flow roughing filters can effectively improve the water quality in the Mullaitivu well field. The findings could be valuable for addressing the water quality challenges in the area and ensuring a safe drinking water supply for the local population.*

Keywords—**Aerator, Groundwater, Iron removal, , Manganese removal, Roughing filter, Turbidity removal**

I. INTRODUCTION

There are many natural resources on the planet and water is one of them. Water is one of the basic needs not only for humans but also for plants, wildlife and other animals. In addition, the requirement of water as raw material is inevitable for all sorts of products in the industrial era. Hence, the contribution made by water to a country's economic development is huge in the present context. Though water is a basic human right, people over 785 million do not have access to basic drinking water facilities. Globally, it is estimated that over 2,000 million people consume drinking water from the faeces' contaminated water sources. Further, it is forecasted half of the world's population will be in water stress regions in another 5 years according to World Health Organization (World Health Organization, 2017). About 97% of the freshwater resources on Earth are available for human use, and one source of water that can be used for daily activities like bathing, cooking, and washing is groundwater.

It is a vital requirement to remove the excessive matter in the potable water treatment process due to its stress on the treatment process, potential to form carcinogenic disinfection byproducts, impact on plant efficiency and impact on aesthetic effect (Nkwonta and Ochieng, 2009). There are many levels of water treatment available and practised at present. Household level, community level and domestic level are the types of water treatment systems commonly available systems. There are three groundwater wells in the drinking water supply scheme, from which 1,440,000 litres of water are being supplied daily. Turbidity, colour, iron and manganese were observed to be above the limit specified in the Sri Lanka Standard, specification for potable water (SLS 614:2013). Therefore, the treatment process of the aerator followed by the roughing filter was constructed to remove the pollutants from groundwater before supplying it to the consumers.

This paper describes an investigation into the effeiciency of the existing water treatment plant concerning the removal of raw water turbidity, colour, iron and manganese in the wellfield of Mullaitivu in Sri Lanka.

There are various conventional water treatment techniques namely: slow sand filtration, roughing filtration, and rapid sand filtration, practised over the years. There are few pre-treatment techniques, to treat raw water to prevent rapid clogging and frequent cleaning of the WTP. However, the roughing filtration process becomes one of the most reliable techniques at present. Either down-flow or up-flow filters are the operating flow pattern in the vertical-flow roughing filters. Vertical-flow roughing filters are designed to have complete submerging of filter media, often with the gravel with various particle sizes in layers (Nkwonta and Ochieng, 2009).

The turbidity removal efficiency using roughing filter in several previous studies is 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

Aeration may be defined as the method of bringing air and water into approaching contact with each other for the objectives of diffusing unwanted water pollutants to air, oxidizing several natural organic matters and enhancing the treatability of water (Ghernaout, 2014)

Conventionally, iron is removed from groundwater by the processes of aeration and rapid filtration. Different mechanisms may contribute to the iron removal in filters; flock filtration, adsorptive iron removal and biological iron removal. Water containing iron can be divided into two main groups: Waters which separate iron just after aeration and waters where iron remains in the solution after aeration for an endlessly long period (Munter, Ojaste and Sutt, 2005).

The extent to which suspended solids in water scattered or absorbed the light is termed turbidity. Nevertheless, the relationship between suspended solids and turbidity in terms of quantitative is not yet proven. The sunlight penetration is resisted by the high turbidity existence in water, which affects the process of photosynthesis. The clarity of water can be discussed in terms of the turbidity level. The transparency or clarity of the water is affected by the suspended solids and colour presence of water. The quality of drinking water is judged by various parameters and turbidity is one of them (Agrawal, Sharma and Sharma, 2020). The famous treatment process practised to eliminate or reduce turbidity is coagulation, sedimentation and rapid sand filtration, by the water supply engineers. There is no evidence that the colour of water is hazardous to human health, hence it is categorized as a secondary pollutant in potable water (Bryant2000). However, the problem with colour is the loss of public confidence in the quality of potable water. The recommended limit of natural colour in drinking water is 15 colour units (EPA2006). While the presence of iron and manganese in drinking water does not pose a health risk, it is problematic when the bacteria are present in soil aquifers and certain surface water. (Rathnakumar2000). Traditionally, aeration and fast filtration are used to remove iron from groundwater. Filters may remove iron by a variety of methods, including biological, adsorptive, and flock filtration. Water that separates iron immediately after aeration and water where iron remains in the solution after aeration for an infinitely long length of time are the two basic categories into which iron-containing water can be categorized (Munter, Ojaste and Sutt, 2005)

Due to their organoleptic characteristics, iron and manganese, which are typically present in groundwater as divalent ions (Fe^{2+} and Mn^{2+}), are regarded as pollutants. While the international requirements are 0.3 mg/L for Fe and 0.1 mg/L for Mn, the maximum acceptable amounts of Fe and Mn in drinking water are 0.3 mg/L and 0.05 mg/L, respectively, in Sri Lanka. Deep filtration and oxidation are the traditional methods for removing iron and manganese from groundwater. For the oxidation of Fe 2+ and Mn 2+, oxygen or stronger oxidants such chlorine and potassium permanganate ($KMnO_4$) are typically utilized.

II. MATERIALS AND METHODS

This study will be an experimental study, involving the collection and analysis of data through controlled experiments. Natural oxidation using an aerator followed by roughing filter was adopted as the treatment method considering the cost-effectiveness, complexity, of the treatment process, filtration rate, water quantity), and space availability at the site.

Water is extracted from three groundwater wells and pumped to the aerator at the initial stage. The daily pumping rate was 1,440,000 litres per day. The fountain-type aerator was used in the treatment plant. The aerator has four drops with a height of 200 mm, 250 mm 250 mm, and 300 mm at the bottom as shown in Figure 1. Water is directed to vertical-flow roughing filters which have four medial filter layers with the particles starting from 10-20 mm, 12-16 mm, 8-12 mm and 4-8 mm with the layer thickness of 300 mm, 300 mm, 300 mm and 450 mm respectively as illustrated in Figure 2. Water is sent bottom to the top surface vertically during this treatment process. Treated water is finally collected to the sump and distributed through the distribution system.

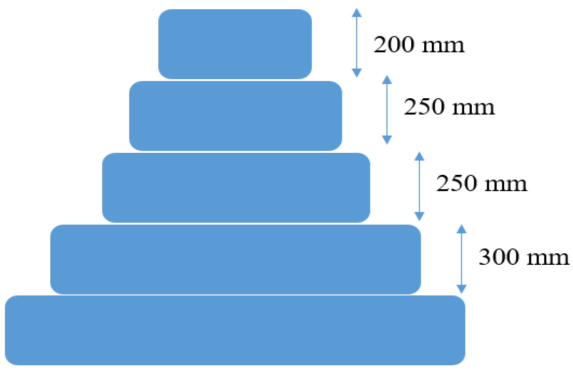

Figure 1. Section of aereator

The treatment plant was operated for continuously 72 hours to study the efficiency of the treatment units. Samples were collected every 6 hours interval before and after aeration, and after roughing filters to test the selected water quality parameters such as turbidity, colour, total iron, and manganese. In addition, raw water from three groundwater boreholes, and treated water from the ground sump and water tower were collected for full water quality testing.

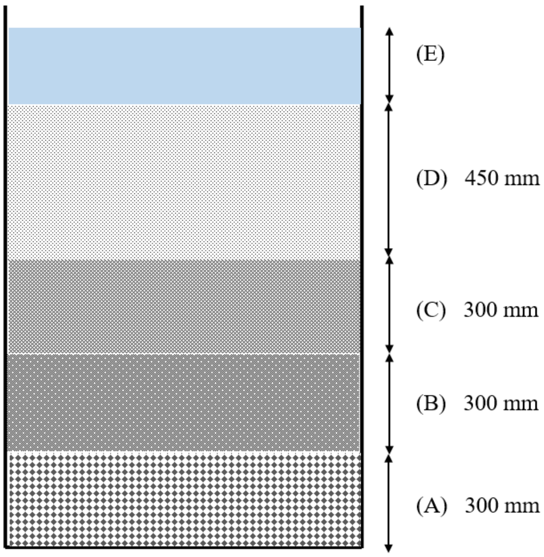

Figure 2. Cross-section of RF

Where;

(A) Filter layer 1 (10-20 mm)
(B) Filter layer 2 (12-16 mm)
(C) Filter layer 3 (8-12 mm)
(D) Filter layer 4 (4-8 mm)
(E) Water column over the filter media

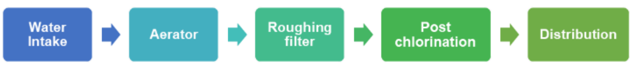

Figure 3. Process chart

Figure 2 shows the coarse and fine aggregates which have been placed in roughing filter as the filter media. Turbidity was measured by a 2100Q turbidity meter at the site laboratory located in the water treatment plant site. Water quality tests were performed based on APHA [3], at Regional Laboratory, National Water Supply & Drainage Board, Jaffna, Sri Lanka.

III. Results and Discussion

As representative test results, Figure 4 shows turbidity in raw water and treated water from the roughing filter (RF) when passing through the aerator and RF, with elapsed time obtained during 72 hours of continuous operation. The result illustrates that the turbidity is removed significantly in the existing treatment methodology of sending through aerator and RF. The turbidity of treated water by RF was observed to be well below the SLS 614;2013 (SLSI, 2013) acceptable limit of 2 NTU in 100% of the treated samples when applying this method. Turbidity of raw water during the testing period by varying in the range of 2.8-10.3 NTU, whereas turbidity of the filtered water from SSF was observed between 0.6-1.9 NTU. The turbidity removal efficiency was calculated by using Equation 1.

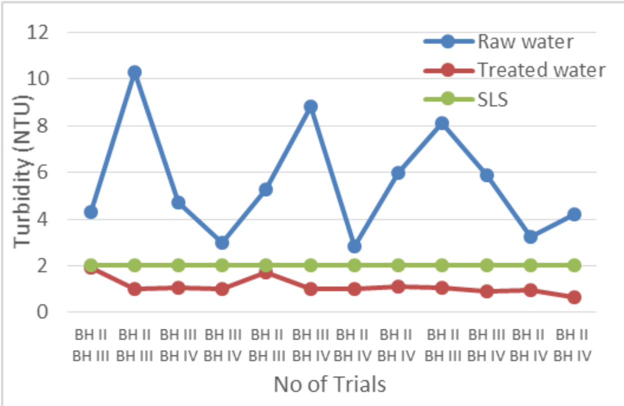

Figure 4. Comparison of turbidity in raw water and treated water

$$\text{Effeciency (\%)} = \frac{(\text{Influent Concentration} - \text{Effluent Concentration})}{\text{Influent Concentration}} \times 100 \qquad (1)$$

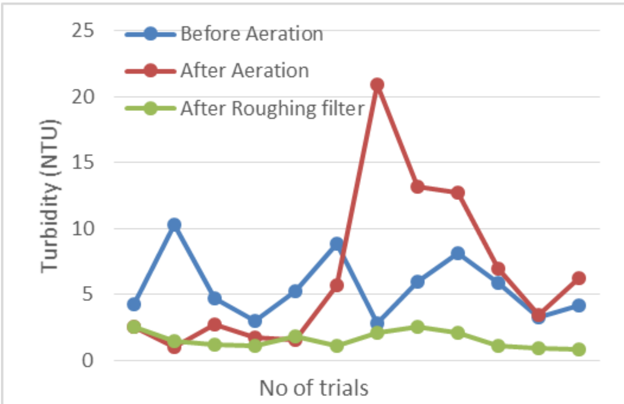

Figure 5. Turbidity variation of treatment process

Figure 5 indicates that 4 out of 12 samples were observed to be reached above the turbidity level of raw water while sent through the aerator. However, the final treated water is well below the turbidity level of raw water. The possible reason for the increase in turbidity level is primarily due to the introduction of air into the water. As air is introduced into the water, it creates bubbles that can trap and carry suspended particles, such as sediment, organic matter, and other contaminants. These bubbles can remain in the water as it passes through the system, leading to higher turbidity levels. Another possible reason could be some substances in the water, like iron and manganese, can be oxidized when exposed to air in the aeration process. The oxidized particles can form solid particles and contribute to turbidity. While aeration can cause short-term increases in turbidity, it is generally beneficial for water quality in the long run, as it helps maintain oxygen levels, reduces odours, and promotes the breakdown of organic matter.

The turbidity removal efficiency by using this method was recorded and plotted in figure 6. It can be observed that the turbidity removal efficiency increases with the number of trails. In addition, it was recorded in a previous study that, a long operation of water treatment plant increased the turbidity removal efficiency (Jenkins, Tiwari and Darby, 2011). The turbidity removal percentage varied between 55% to 88% and the average turbidity removal percentage was 73%. The turbidity removal efficiency in a roughing filter increases with the number of trials primarily due to filter media conditioning. A roughing filter is typically filled with a coarse filter media, such as gravel or sand, that has not been pre-treated or conditioned. With each trial, the filter media becomes better conditioned as the particles and impurities start to accumulate and clog the pore spaces. This conditioning process leads to finer particles being trapped more effectively, thus improving turbidity removal efficiency over time.

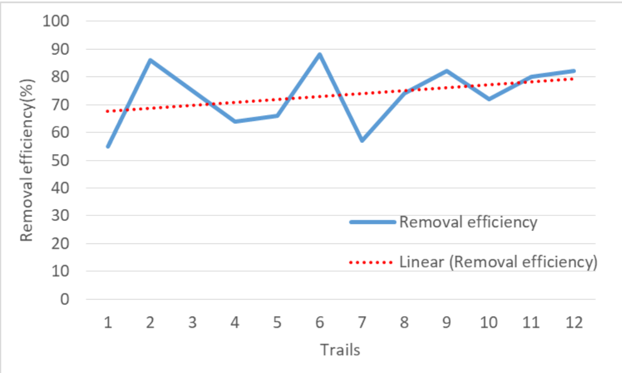

Figure 6. Turbidity removal effieciency

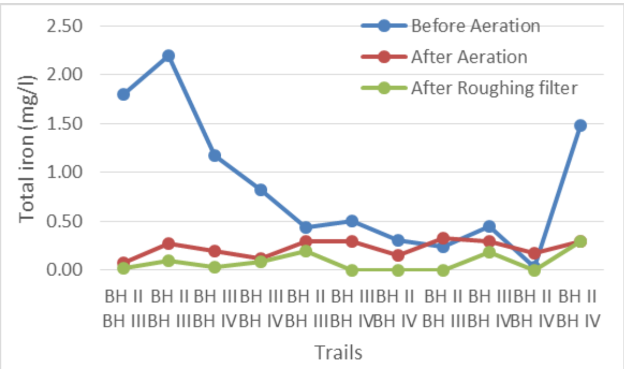

Figure 7.Total iron variation of treatment proccess

As shown in Figure 7, there is a sudden removal of total iron during the aeration process. The concentration of total iron before and after aeration is in the range of 0.24-2.20 mg/l and 0.03-0.33 mg/l respectively. The sudden removal of total iron during the aeration process can be attributed to the phenomenon of iron oxidation and subsequent precipitation. The dissolved ferrous iron (Fe^{2+}) in the water is readily oxidized by dissolved oxygen (O_2) present in the air. The reaction can be represented in equation (2)

$$4Fe^{2+} + O_2 + 10H_2O \Rightarrow 4Fe(OH)_3 + 8H^+ \quad (2)$$

The oxidized iron forms ferric hydroxide ($Fe(OH)_3$) as a solid precipitate. Ferric hydroxide is an insoluble compound that can no longer remain dissolved in the water and settles down as a visible reddish-brown sediment. The sudden removal of total iron occurs because the dissolved iron is converted into its solid form (ferric hydroxide) during the aeration process. As the iron precipitates out of the water, it gets physically separated from the water, leading to a significant decrease in the total iron concentration.

The total iron removal efficiency varied between 55% to 100% and the average total iron removal percentage was 88%.

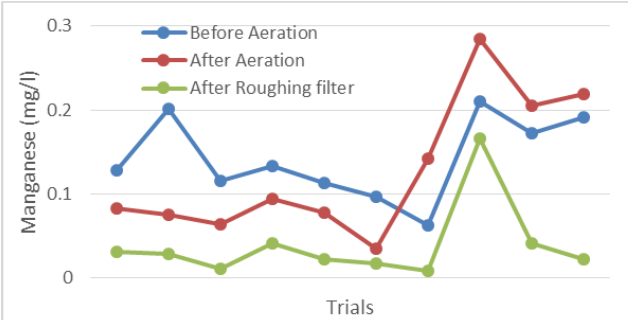

Figure 8. Manganese variation of treatment proccess

There are reductions and increases during the removal of manganese during the aeration process. However, the manganese level is well below the raw water after filtering via RF. The primary reason for manganese level reduction is physical filtration. A roughing filter is typically filled with coarse filter media, such as gravel or sand. As water passes through the filter bed, suspended particles, including manganese-containing particles, get physically trapped in the void spaces between the filter media. This process helps to remove larger particles from the water, including manganese particles. In addition, in the presence of oxygen, manganese in water can be oxidized from the soluble divalent form (Mn^{2+}) to the less soluble trivalent form (Mn^{3+} or Mn^{4+}). Once oxidized, manganese can form solid manganese oxides or hydroxides, which then become part of the sediment and are removed during the filtration process. Another possible reason could be, biological activity within the roughing filter can play a role in manganese reduction. Microorganisms in the filter may promote the oxidation of soluble manganese to its solid form, aiding in the removal of manganese from the water.

The manganese removal efficiency varied between 21% to 91% and the average manganese removal efficiency was 75%.

IV. Conclusion

The research objective was to evaluate the performance of the combination of aeration and roughing filter in terms of turbidity, colour, total iron and manganese removal from groundwater to supply potable water. The result illustrates that the colour and total iron are removed significantly by adopting this methodology with the removal efficiency of 84% and 88% respectively. It can be observed that the treated turbidity level is well below the threshold limit of 2 NTU, the treated manganese level is well below the limit of 0.1 mg/l, and the treated total iron level is well below the limit of 0.3 mg/l specified in SLS 614;2013 for drinking water, in most of the trails when using this method. The turbidity removal efficiency was observed to be increased with the days of operation. Further, it is recommended to include prechlorination to enable better oxidation and thereby increase the total iron and manganese removal efficiency. By this means turbidity and colour removal efficiency will be improved. The existing backwash valve arrangement should be changed to facilitate quick/sudden backwashing to maintain optimal filtration efficiency and minimize downtime

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