Effectiveness of chlorine as a pre-oxidation mechanism in water treatment for turbidity removal in groundwater as a water efficiency strategy

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***Abstract* — Groundwater supply has been one of the pillars of socio and economic development, especially in the dry regions of Sri Lanka, where reliable water sources are very scarce. With the rising water demand, water conservation through recycling and reusing has become an important strategy in a sustainable built environment. The Murunkan aquifer is one of the most utilized aquifer systems in Northern Province. The average extraction from the Murunkan aquifer is approximately 10,000 m^3/d. The yield is nearing saturated, thus leading to a few water quality variations. Variations in turbidity level in Murunkan groundwater sources could be a consequence of precipitation of insoluble reduced iron (Fe^{2+}), manganese (Mn^{2+}) and other oxides. The study is focused on investigating the effectiveness of chlorine as a pre-oxidation mechanism in rapid sand filtration for turbidity removal in groundwater. The pilot filter consists of particle sizes of 25mm, 16mm, 10mm, 2-5mm with a layer thickness of 75 mm, 50mm, 30mm, and 50mm, respectively, and sieved ordinary silica sand as filter media with 700 mm layer thickness. The chlorine solution is added at the inlet point of the filter. A retention time is maintained between 20-25 minutes to allow oxidation above the sand bed within the rapid sand filter model. The effluent from the filter was tested for turbidity based on APHA standards for 15 trials. Raw water turbidity ranges between 0.27-3 NTU, while treated water turbidity ranges between 0.21-0.68 NTU. The maximum turbidity removal percentage was 77% while turbidity removal was observed in 60% of samples. It is also found that there is a trend in increasing removal percentage with the increase of raw water turbidity and the number of trials conducted, however, removal efficiency does not have any definite trend with chlorine concentration.**

Keywords—Chlorination, Groundwater, pre-oxidation, Rapid Sand Filtration, Turbidity

I. INTRODUCTION

Water quality has developed into a critical issue with the rapid population increase and it is a vital concern for humans since it is directly linked to the well-being of the people. Global water consumption is growing every day at a quite higher rate when compared with world population growth. It is forecasted that; a severe shortage of potable water will occur worldwide by 2050. Both surface and groundwater sources are being used to fulfil drinking and secondary water needs. Groundwater sources are very crucial in the global drinking water supply as it holds around 30% of the freshwater quantity on earth. Groundwater supply has emerged as a pioneering factor of socio, economic and sanitation development in Sri Lanka, especially in the Northern province where there are no perennial rivers. Pipe-borne water supply coverage of the Northern province is around 12% while the national coverage is around 50% at present. Hence, most of the dwellers in the region tend to use common and own dug wells and tube wells scattered over the area for decades.

The potable water supply of the Mannar district solely relies on groundwater sources. The availability of groundwater in the Mannar district is limited and is being contaminated by human activities and saltwater intrusion. The groundwater is extracted from the Murunkan aquifer, characterized as a Deep Confined Aquifer of the Sedimentary Limestone and Sandstone Formations Panabokke and Perera [1]. The drinking water need of 40% of the Mannar district's population is covered by several deep wells in Murunkan owned by the National Water Supply and Drainage Board (NWS&DB). The average daily extraction of groundwater from the Murunkan aquifer is 10,000 cubic meters per day and the yield is nearing saturated, thus leading to a few water quality variations in the recent past. Maintaining turbidity levels within the acceptable limits stipulated in the

ISBN: 978-624-6150-05-1

Sri Lankan drinking water standards (SLS 614:2013) is compulsory to maintain customer-satisfied utility service. A wide variety of suspended matter, such as clay, silt, finely divided inorganic matter and various Natural Organic Matter (NOM), soluble coloured organic compounds, and other microorganisms shall be the possible cause for turbidity in groundwater. Turbidity in Murunkan groundwater sources could be a consequence of inert clay or chalk participles or the precipitation of insoluble reduced iron (Fe^{2+}), manganese (Mn^{2+}) and other oxides.

The objective of this study is to investigate the effectiveness of chlorine as a pre-oxidation mechanism in Rapid Sand Filtration (RSF) for turbidity removal in groundwater. Finding an efficient mechanism for the turbidity removal in groundwater would bring a sustainable solution for ensuring the customers are satisfied with a sustainable potable water supply service which shall ensure the optimum consumption of water without wasting due to turbidity.

II. Literature Review

A. *Sources and the effect of turbidity*

The measure of water's relative clarity or cloudiness is termed "turbidity". There are many causes for turbidity in water, however, the possible causes could be a wide variety of suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, and other micro-organisms. Further, inert clay or chalk particles or the precipitation of insoluble reduced iron (Fe^{2+}) and other oxides shall also cause turbidity in some groundwater sources. Treatment plant design and operation depend on the turbidity of raw water as well. The Nephelometric Turbidity Unit (NTU) is used to measure turbidity levels. Turbidity above 4 NTU may be noticeable and consequently objectionable to the consumer's NWSDB Design Manual [2].

Since turbidity is an aesthetic component of drinking water quality, it is essential to maintain below 2 NTU as specified in the Sri Lankan drinking water quality standards (SLS 614:2013). Exceeding turbidity levels may cause health effects due to suspended particles or colloidal caused by inorganic, organic or microorganisms (bacteria, viruses and protozoa) typically attached. Aesthetic problems are also considered a reason for reducing the confidence level of the public in water supply safety. Moreover, excess turbidity may cause various operational issues such as hindering the water treatment process, reducing treatment effectiveness, shielding microorganisms against disinfectants, de-sorption of toxic materials (e.g. heavy metals) and releasing hidden pathogenic organisms. The turbidity of treated water is a key measure of its suitability for disinfection. World Health Organization (WHO) has defined the turbidity level should be less than 0.5 NTU for effective disinfection.

B. *Turbidity removal*

Removal of turbidity may be achieved by coagulation, flocculation, sedimentation and rapid filtration or by a biologically mediated slow sand filtration process. Rapid sand filters must be provided with efficient pre-treatment for water with a turbidity of more than 5 NTU. Coagulation/flocculation is a widely used method applied in water treatment to remove turbidity, colour and Natural Organic Matter (NOM). Chemical coagulants used in water treatment such as Aluminium Sulphate are generally expensive. The ability of three plant materials to act as a natural coagulant to remove turbidity was evaluated Muthuraman & Saikala [3].

RSF and Slow Sand Filtration (SSF) are identified as widely used and effective processes for turbidity removal. Although the SSF has advantages such as high treatment efficiency, low cost, easy operation and water conservation, it occupies a considerable area of land compared with RSF. In addition, since the SSF has biological treatment, pre-treatment and usage of chemicals are limited.

III. Materials and Methods

Chlorination followed by rapid sand filtration was selected as the treatment method for the removal of turbidity, although the most recommended method for turbidity removal is coagulation, flocculation followed by sedimentation. Nevertheless, the whole treatment unit requires huge capital costs, operational cost, and land space. Since the chlorine oxidizes dissolved Fe^{2+} and Mn^{2+} ions into insoluble compounds which could be trapped in filtration, employing chlorination is effective for the removal of turbidity that occurred due to Fe^{2+} and Mn^{2+} ions.

A. *Filter arrangement*

A prototype filter was made with 160mm diameter and 4m length of a uPVC pipe piece and filter material, which was selected through a sieve analysis test. The pilot filter consists of particle sizes of 25mm, 16mm, 10mm, 2-5mm with a layer thickness of 75 mm, 50mm, 30mm, and 50mm, respectively, and a filter media with a 700 mm layer thickness.

Natural sand was selected as filter media and effective size (D_{10}) and Uniformity coefficient (D_{60}/D_{10}) were determined as 0.425 mm and 2.77, respectively. The particle size distribution curve was obtained as depicted in Fig. 1. Then the particles and filter media were placed as layers from bottom to top respectively as shown in Fig. 2. The water column above the filter top was maintained at around 2880mm in height.

Filter inlet, outlet and backwashing point were connected by pipelines with valve arrangements. A small feeder mechanism conveys the chlorine solution with different concentrations and a separate pipeline was provided from the chlorine tank to add chlorine for oxidation. Chlorine solution was added on top of the water column as presented in Fig. 2.

B. Oxidation

Reaction time is also a vital factor for proper oxidation and 20-25 minutes of retention time with chlorine was maintained. 15 no. of trials were conducted by changing the chlorine concentration in the raw water.

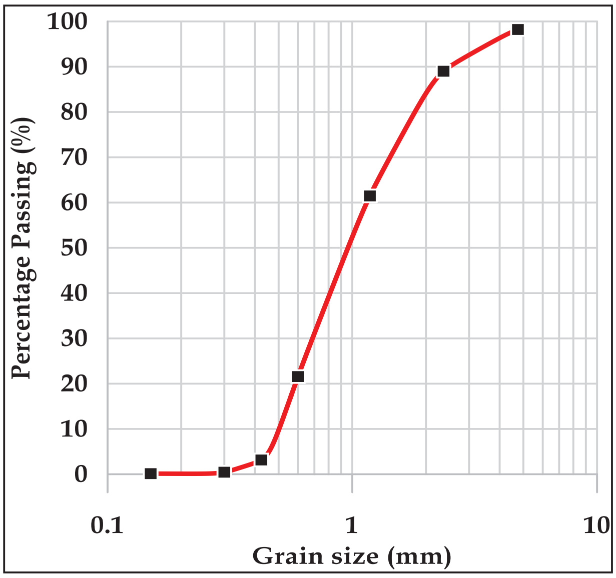

Fig. 1. Particle size distribution curve

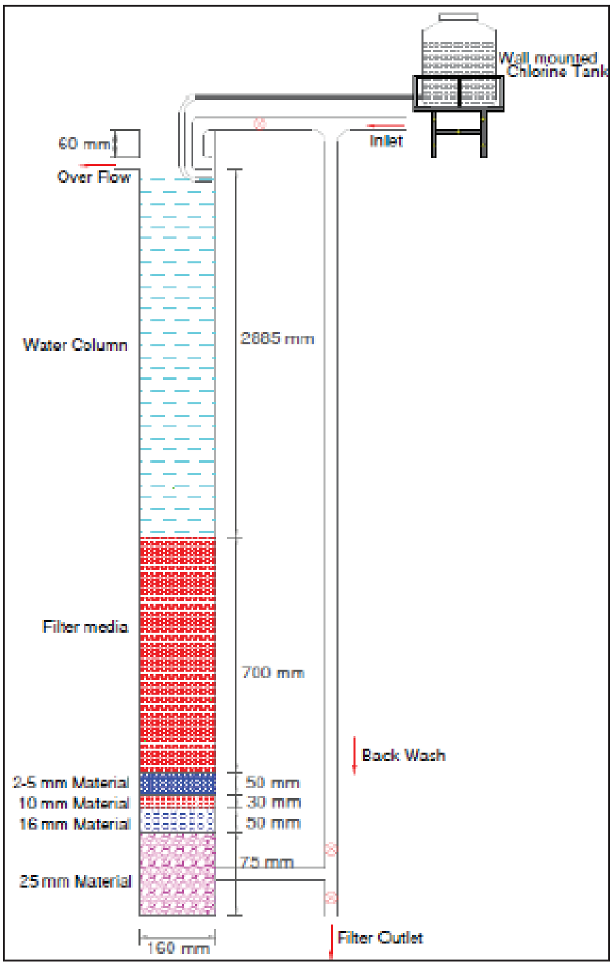

Fig. 2. Filter model

Both raw water and treated water samples were tested according to APHA 2130 B method in this study [4].

IV. RESULTS AND DISCUSSION

Raw water turbidity ranges between 0.27-3 NTU while treated water turbidity ranges between 0.21-0.68 NTU. Groundwater sources are less vulnerable to contaminat from various natural and anthropogenic sources than surface water sources. They are less exposed to the atmosphere. Thus, suspended substances, insoluble precipitated ions and soluble coloured organic compounds play a vital role in creating turbid water. When rainwater seeps through soil pores it liquifies minerals and releases various ions into aquifers. It was observed that water gets discoloured after exposure to the air. Oxidation of soluble ions into insoluble precipitates may be the possible reason for that.

ISBN: 978-624-6150-05-1

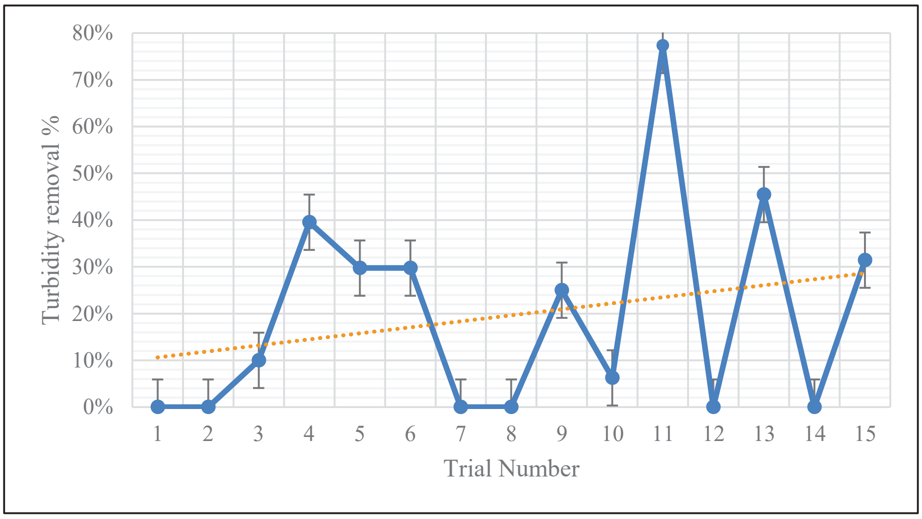

Fig. 3. Variation of turbidity removal over the trials

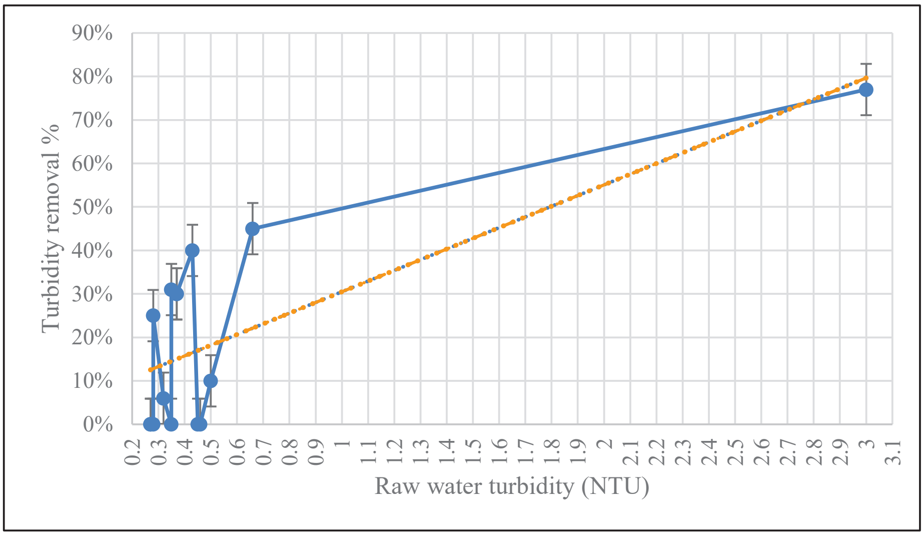

Fig. 4. Variation of turbidity removal with raw water turbidity

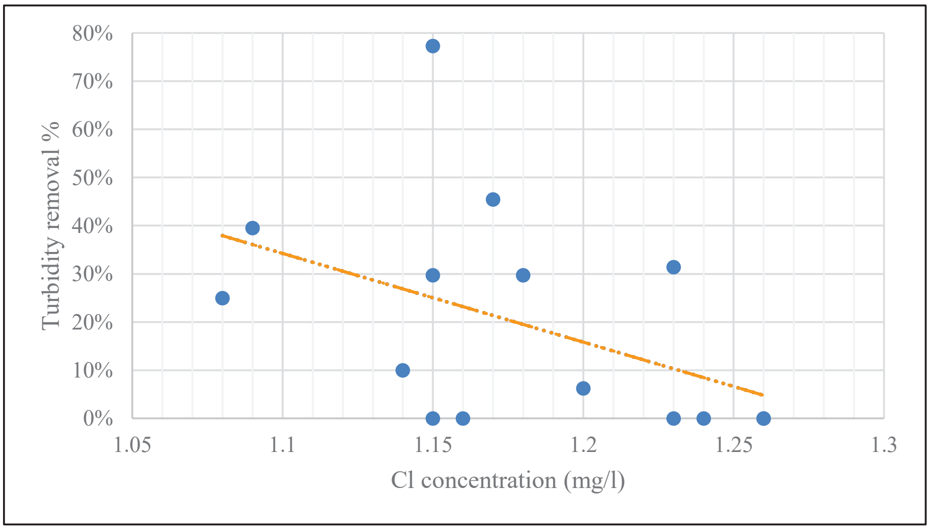

Fig. 5. Variation of turbidity removal with Cl concentration

ISBN: 978-624-6150-05-1

Hypochlorous acid (HOCl) and Hydrochloric acid (HCl) are formed when chlorine reacts with water. Both hypochlorous acid and hypochlorite ions are included in the free available chlorine, which can react with dissolved ions and organic compounds present in water. Recommended residual chlorine concentration should be 0.5- 0.8 mg/L when treated water reaches the clear water tank. Further, when adequate levels of chlorine are in contact with organic matter, there is a potential for the formation of Trihalomethanes (THM) NWSDB Design Manual [2]. The filtration rate was reduced, and the filter outlet's turbidity was increased after several trials due to the clogging of filter pores. Therefore, regular backwashing is required to maintain filter efficiency.

Turbidity removal efficiency shows fluctuations over the 15 trials conducted as depicted in Fig. 3. Intermittent filter clogging and regular backwashing might be the major cause for fluctuating the removal efficiency. Nevertheless, it is observed that filter performance in removing turbidity is increased with the increse of trials.

Further, removal efficiency is affected by the turbidity level of raw water. Fig. 4. shows the variation of removal efficiency of the filter. The trend line shows that the removal efficiency is increasing with the increase in raw water turbidity.

Fig. 5. shows the variation of removal efficiency with chlorine concentration. Removal efficiency does not have any definite trend with chlorine concentration. The maximum turbidity removal percentage was 77% while turbidity removal was observed in 60% of samples.

Many people correlate turbidity with safety and consider turbid water unsafe for human consumption, especially for drinking. However, most particles that are contributing to turbidity have no health significance. This response is exacerbated when consumers have been used to consume high-quality filtered water. Consumers may use lower turbidity alternatives that may not be safe to drink less water if they lose confidence in a drinking-water supply. Any consumers' complaints about unexpected turbidity should always be considered and investigated because they could reflect significant faults or breaches in distribution systems which can drastically affect the business and goodwill of the water utility organizations. WHO [5].

V. CONCLUSIONS

As a pilot study, a filter was erected and raw water was conveyed through the filter model with pre-oxidizing by chlorination with different concentrations, and effluent was collected at the bottom and tested for turbidity. Based on the results, there was a considerable reduction in turbidity in treated water during the treatment process. It was found that there's a trend of increasing removal percentage with the increase of raw water turbidity. In addition, filter efficiency was found to be increased with the number of trials conducted. Future studies shall be carried out by, changing the pH value of the raw water to find the appropriate pH value for better oxidation and using different sized filter media to find suitable particle size of the filter media for efficient turbidity removal.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance given by the National Water Supply and Drainage Board during this study.

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ISBN: 978-624-6150-05-1