Quality assessment of raw and treated water and efficiency of the water treatment plant coupled with Dunumadalawa reservoir in Kandy, Sri Lanka

Abstract

Water is a fundamental requirement for all life activities and is essential to humans, animals, and plants.Various physicochemical andbacteriological parameters can beused in assessing quality of drinkingwater.This study was carried out to evaluate the efficiency of water treatment plants by assessing water samples before and after treatment and comparing results withthe Sri Lankan Standards (SLS) and the standards set by World Health Organization (WHO) for drinking water.Seven water samples were collected and selected physicochemical and bacteriological parameters were determined.The results indicated that all parameters of the chlorinated water were within the permissible levels of SLS, and WHO. Therefore, it can be concluded that the overall efficiency of the existing treatment plant was at a satisfactory level. Special concern should be given forthe monitoring process and propertechnical maintenance of theexisting water treatment plant.

Keywords–Water treatment plant, physicochemical parameters, bacteriological parameters, quality of water

Introduction

Water is one of the most important and priceless natural resources. It is essential in all living organisms, from the simplest microorganisms and plants to the most complex living system known as the human body (WHO, 2011).Unfortunately, water that is clean, pure, and safe only exists briefly in nature and is immediately polluted by prevailing environmental factors and anthropogenic activities. Access to safe drinking water has improved over the last decades in most parts of the world. However, approximately 1.1 billion people still lack access to safe potable water, and over 2.6 billion worldwide do not have access to adequate sanitation, which contributes to the spread of water-borne diseases (Adebisi *et al*., 2016).

Water is treated conventionally in different parts of the world to improve its quality, so it can be used for many purposes, such as drinking, manufacturing, or medical purposes. The original aim of treating water was to improve the aesthetic value of drinking water. Later on, techniques for improving the taste and smell of drinking water were introduced. Currently,the purification process includes physical procedures such as settling and filtering, as well as chemical processes such as coagulation, flocculation, and disinfection which may be used to separate sediments and pathogenic microorganisms from drinking water to provide a safe source of water supply.

In Sri Lanka, the highland massif determines the inland water resources, which consist of 103 river basins and the quality, and the quantity depend on its geological formations (Silva, 1999).One of the most pervasive problems in numerous parts of Sri Lanka has been recognized as a lack of access to clean drinking water. In the north-central region of the country, excessive levels of pesticides and fertilizers, as well as high fluoride content in groundwater, have been recognized as the leading underlying causes of Chronic Kidney Disease.However, appropriate research and treatments are still missing. To anticipate unforeseen dangers and apply appropriate water resource management methods to resolve those concerns, it would be advantageous to examine the water quality in inland water resources.

Dunumadalawa forest reserve, also popularly known as Wakarawatta after its original estate name -Walker’s estate, comprises mainly a secondary-growth forest since the site has been used earlier for tea, coffee, and cocoa plantations. It has been allowed to regenerate with some plant species being reforested naturally and was designated a forest reserve. It is one of the most remarkable forest reservations in the Kandy district, along with two other reservations; UdawattakaleandHantana forest areas. The forest consists of different habitats, such as woody areas, grass patches, pine plantations, abandoned tea, coffee, and cocoa plantations, and several permanent and temporary lentic and lotic water bodies. The reserve forms the catchment and protects the watershed of two natural reservoirs known as Dunumadalawa and Roseneath reservoirs (Dharmasena et al., 2001). Water purification plants from two reservoirs fulfill 10% of the city’s drinking water requirement. Spill water from the Dunumadalawa reservoir falls into the MedaEla Canal, which carries spilled water from the Kandy Lake to the Mahaweli River.

Dunumadalawa reservoir and the water supply scheme were constructed by the former British rulers in the 1870s to supply clean drinking water to the residents of Kandy City. In the Strategic Cities Development Project/MM & WD, carried out during the period from 2016 to 2017, the existing purification plant was augmented by introducing a new aerator and a flocculator, a new chemical dosing system for the proper removal of colloidal and suspended particles of the water, a plate settler to remove the suspended material from water through a process of settling, new nozzles for the existing five rapid sand filters and a sludge drying bed (Fig. 01). The ultimate aim was to convert the partial conventional purification process into a highly efficient complete process. (Environmental Screening Report, Strategic Cities Development Project)

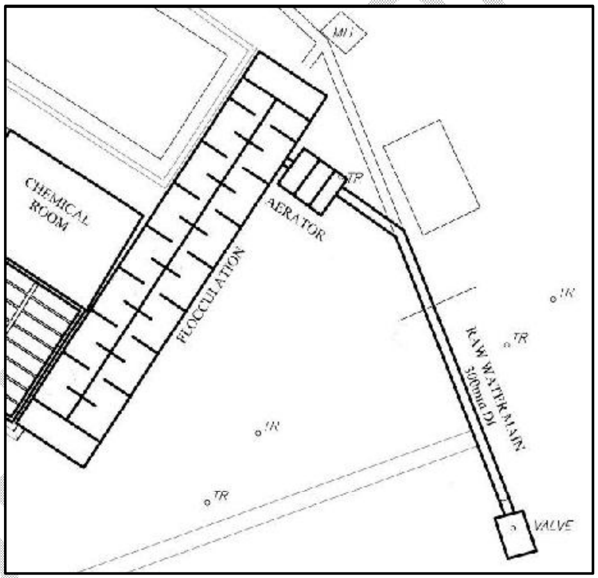

Figure 01: Newly introduced Aerator and Flocculator of the treatment plant

(Source: Environmental Screening Report,Strategic Cities Development Project)

Design modifications of a purification plantcould result in an increase inthe efficiency of the treatment process and also improve the quality of drinking water.Thus, this study was designed to assess several significant physicochemical and bacteriological characteristics of raw and purified water in the Dunumadalawa water purification plant, to gauge the quality of the drinking water and the effectiveness of the modified purification plant currently functioning at the forest reserve.

Materials and methods

Study site

Dunumadalawa forest reserve (7^{o}17'00" N; 80^{o}38'49" E; 548-972 m above sealevel), situated at the northern end of the central massif of SriLanka, isapproximatelyof about480 hectares in extent of terrestrial and aquatic habitats. The reserve forms the catchment and protects the watershed of two natural reservoirs, Dunumadalawa and Roseneath. This research is based on the water supply scheme of the Dunumadalawa reservoir, which was constructed by the former British rulers in the 1870s by constructing a dam across the Dunumadalawa stream to provide drinking water to the city's residents.

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Selection of Sampling Points

Water samples were collected from the following seven points.

1. Three samples along the natural stream (S1, S2, and S3)

S1- Stream 1

S2 – Stream 2

S3 – Main stream carrying water from S1 and S2 to the reservoir

2. L1- Sample from Dunumadalawa reservoir (Fig. 2a)

3. Three samples from the water purification process (P1, P2, and P3)

P1- Aerated Water after the aeration process (Fig. 2b)

P2 – Water collected from the sedimentation tank after coagulation and flocculation (Fig. 2c)

P3 – Chlorinated water ready to distribute to consumers (Fig. 2d)

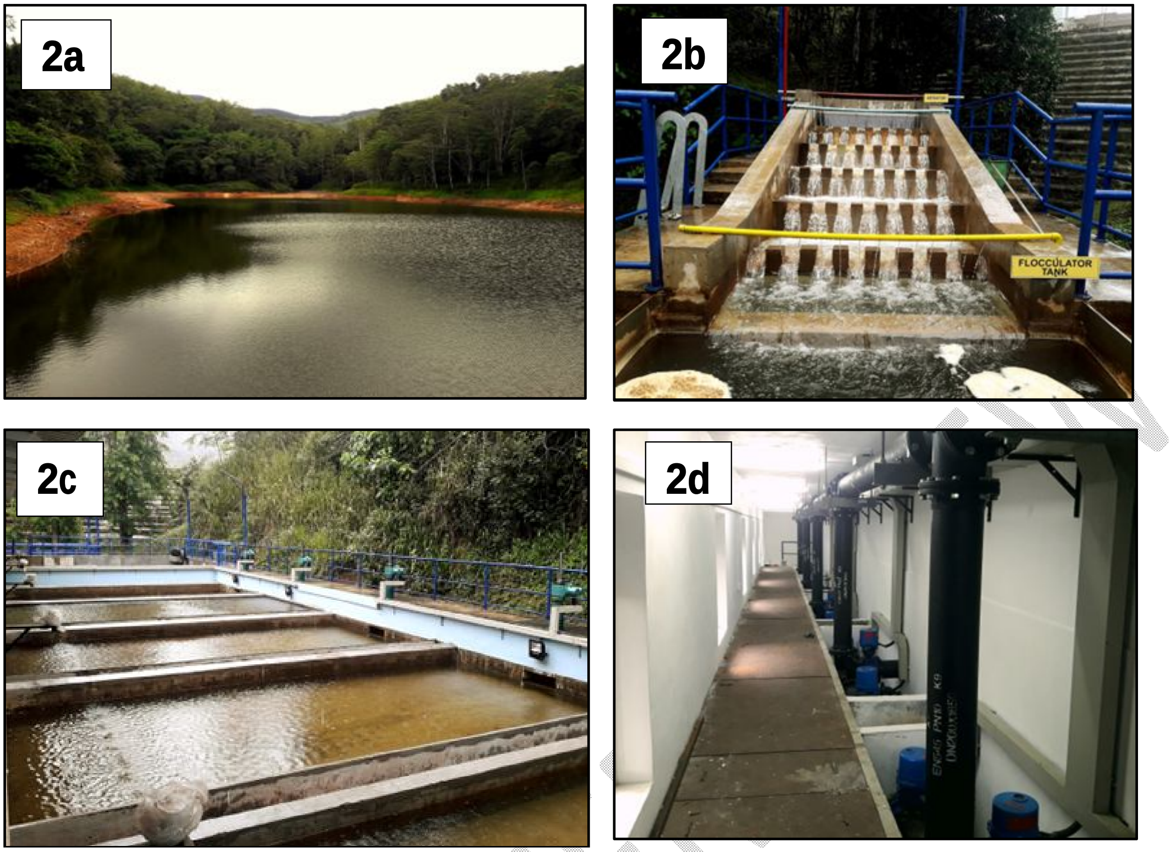

Figure 02: Sample collection points;Dunumadalawa reservoir (2a), Aeration tank (2b), Sedimentation tank (2c), Distribution unit of chlorinated water (2d)

(Source: Strategic Cities Development Project)

Sample Collection

Triplicate samples were collected from each of the seven different locations listed above, during the day between 9.00 – 11.00 am. Samples were collected from each location into 500 mL plastic bottles previously cleaned by washing with nonionic detergents and then rinsed with tap water, followed by thetarget water at each location three times before filling. Water samples for bacteriological analysis were collected into pre-sterilized 500 mL stoppered glass bottles. Immediately following collection, samples were labeled correctly, and delivered to the Regional Laboratory (Kandy South), National Water Supply and Drainage Board, Old GalahaRoad, Peradeniya, Sri Lanka.

Analysis of Physicochemical Parameters

The physicochemical parameters,including turbidity, pH, alkalinity, Total Dissolved Solids (TDS),hardness, chloride, total phosphate, fluoride, total iron, and calcium, were analyzed. The results of each parameter were compared with the guidelines and standards set by Sri Lankan Standards (SLS 614: 2013) and World Health Organization (WHO, 2011) (maximum permissible level for drinking water).

Bacteriological Parameters

The Membrane Filtration (MF) technique was used to test the bacteriological quality of collected water samples. Each water sample was filtered using the filtration apparatus with afilter paper of 0.45 μm pore size which retained the bacteria on it. These filter papers were incubated on M Endo medium, and enumerated the typical colonies grown on each filter paper.

Results and discussion

Physical parameters of water

Turbidity is a measurement of the cloudiness of water, and the values are expressed in Nephelometric Turbidity Units (NTU).It was one of the significantphysical parameters investigated in this study (Fig. 03).

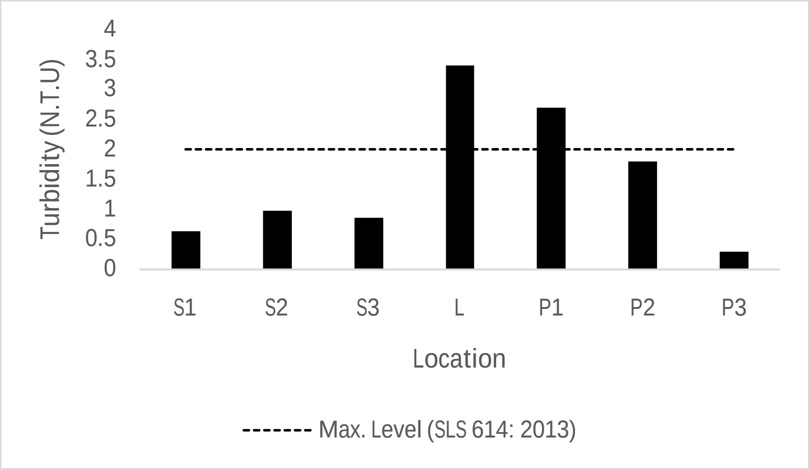

Figure 03- Variations in turbidity of collected water samples

Turbidity is one of the principal physical characteristics used to determine the potability of water. According to the SLS614:2013 guidelines,Turbidity should ideally be below 2NTU,and the appearance of water with a turbidity of less than this value is usually acceptable to the consumers. The standard recommended maximum turbidity limit, set by WHO, is 5 NTU. According to the results, the sample collected from the reservoir (L) showed the highest turbidity value (3.4 NTU), followed by the sample obtained from the aeration tank (2.7 NTU), and both values were above the maximum permissible level ofSLS 614:2013 guidelines, but below the WHO standards. Following the addition of chlorine to the water during the disinfection process, a sample was collected, and a minimal turbidity of 0.29 NTU was found.

Different materials that cause water to be turbid include clay, silt, tiny inorganic and organic matter, algae and other phytoplankton, and many other microscopic organisms.Several of these pollutants can build up in the reservoir (L), resulting in the maximum turbidity. Aeration is a process thatremoves some pollutants, such as iron and manganese, and similarly color, turbidity, odor, and taste. The raw water from the reservoir directly enters into the aeration process, and the sample collected from the aeration tank showed a considerable reduction in turbidity.

Total dissolved solids

Another important physical factor in determining the water quality is the Total Dissolved Solids (TDS), which could influence and connectwith increasing turbidity, total hardness, and alkalinity of a given water sample.Inorganic salts and a small amount of organic matter make up TDS in water. Calcium, magnesium, potassium, and sodium are examples of inorganic salts that are frequently found in water as cations and carbonates, nitrates, bicarbonates, chlorides, and sulfates are examples of anions common in water (Saad et al., 1998).

All tested water samples had TDS values less than 60 mg/L, recording a maximum of 57.2 mg/L from the sample collected from stream 2 (S2) with an average of 46.3 mg/L (Fig. 04).According to the SLS and WHO standards, the highest permissible level for total dissolved solids are 500 mg/l and 600 mg/l, respectively. Accordingly, total dissolved solid values for all tested samples laywithin desirable range for drinking purposes.

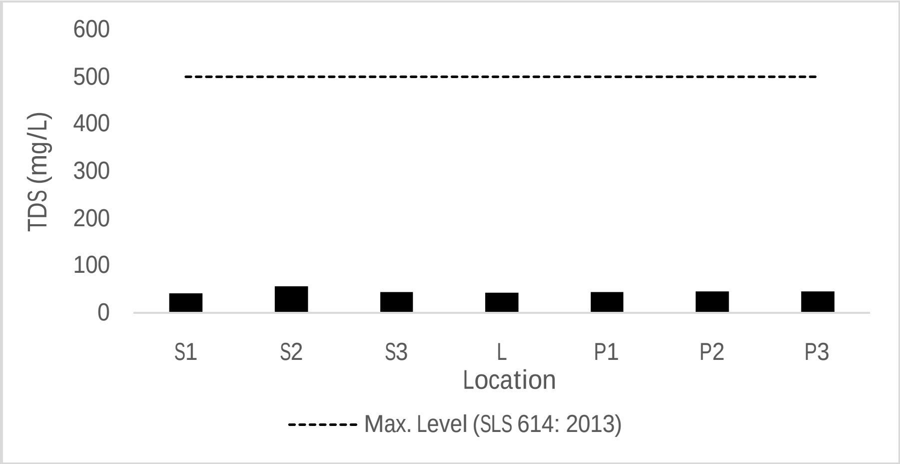

Figure 04 – Variation in total dissolved solids of collected water samples

According to the results of all examined samples, the detected levels of cations (calcium, manganese, and iron) and anions (fluoride, phosphate, nitrite, and sulfate)were found to be within the maximum permissible levels set by SLS and WHO. Iron, sulfate, and nitrite were absent in many samples in detectable amounts. Compared to the SLS standard of 100 mg/L, the level of measured calcium was shallow, with an average value of only 10 mg/L. However, each water sample had an iron content of roughly 0.1 mg/L, with thehighest level of 0.24 mg/L for the sample taken from the reservoir (L) (Fig. 05). Maximum permissible limit of SLS and WHO for the presence of iron in wateris 0.3 mg/L and none of the samples exceeded the standards.

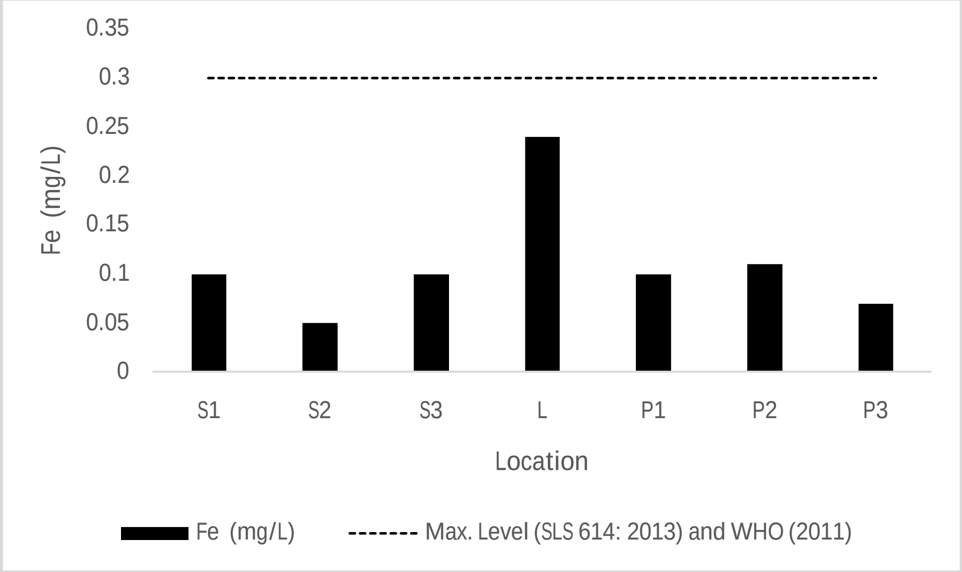

Figure 05 – Variation in levels of iron of collected water samples

Iron is a compound naturally found in high quantities in lake sediments. Iron is one of the controlling factors regulating phosphorous (P) release/uptake by sediments in water bodies under anaerobic and aerobic conditions (Olila and Reddy, 1997). Phosphate precipitation using Fe salts is a relatively common practice in municipal wastewater treatment facilities.The findings of this study demonstrated that the high amount of iron in the water sample taken from the reservoir (L) (Fig. 05) had the effect of removing phosphate, leaving the sample taken from the reservoir with the lowest level of phosphate (Fig. 06).

pH is a crucial factor in evaluating the acid–base balance of water. The pH is essentially determined by the amount of dissolved carbon dioxide, which forms carbonic acid in water. The pH range for drinking water recommended by both SLS and WHO is 6.5 to 8.5. The current investigation revealed that the pH values of all samples collected were in the range of 6.56–7.42, which were in the range of WHO and SLS standards (Fig. 07). Slightly acidic pH values were obtained from the two samples collected from streams S1 and S2, which flow through the forest until they meet and form the main stream which carries water to the reservoir.

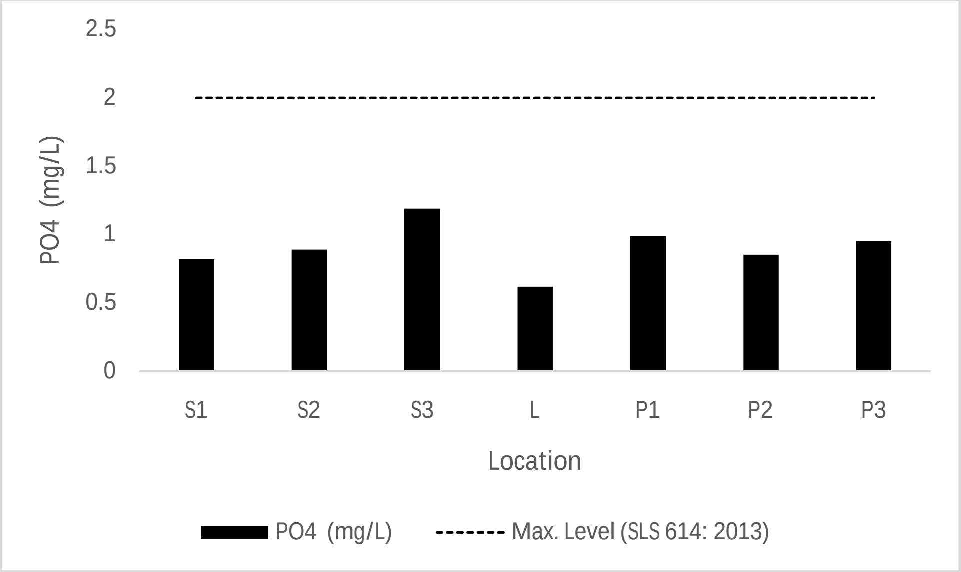

Figure 06 – Variation of the phosphate levels of the collected water samples

Chemical parameters of water

pH

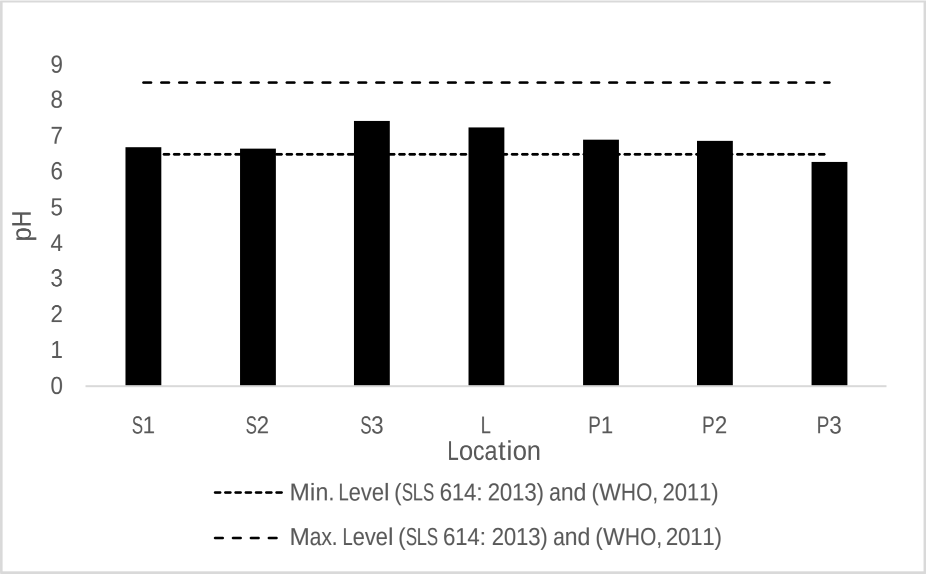

Figure07– Variation in pH of collected water samples

The pH ofdrinking water has no immediate direct effect onhuman health but can cause some indirect healtheffects by making changes in other water qualityparameters such as solubility of metals andsurvival of pathogens (Zabed et al., 2014). Literature data (Kim et al., 2011)demonstrated that at low pH, water can becomecorrosive and cause damage to equipment, sinceit can increase the leaching of metals such as copperand lead from pipes and fixtures.

Total hardness and alkalinity

The values of water quality parameters such as hardness, alkalinity, and total dissolved solids of all samples collected from different locations were considerably lower than the recommended limits of SLS.

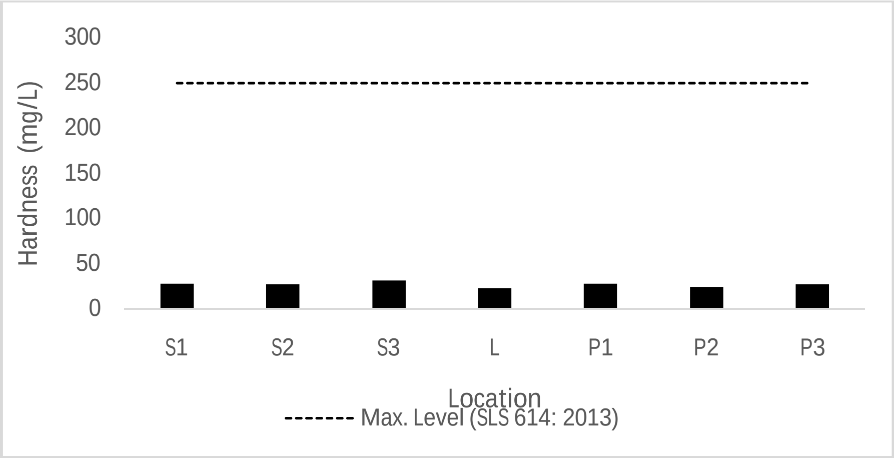

Figure08– Total hardness variation of collected water samples

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium, which can be found in sewage and industrial wastes (Joshi et al., 2014). In all seven water samples tested, the hardness value ranged from 22 to 31 mg/L. The SLS standard value of hardness is 250 mg/L, and none of the samples exceeded the maximum permissible limit for hardness value in SLS standards (Fig.08).

The alkalinity of a water sample is determined by the amount of hydroxide and carbonate ions present. The WHO and SLS have established 500 mg/L and 200 mg/L as the maximum allowable alkalinity values, respectively. As depicted in Figure 09, the minimum and the maximum levels of alkalinity of the tested water samples were 24 mg/L and 32 mg/L, respectively, and neither of these values exceeded the upper limits established by both WHO and SLS.

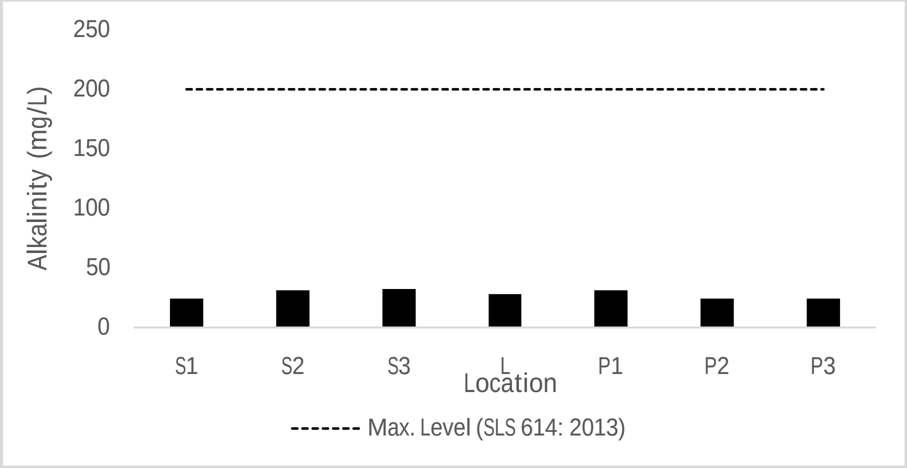

Figure09 – Alkalinity variation of collected water samples

Bacteriological analysis of water

Bacteriological quality is the primary issue in any water quality assessment program, especially those used for domestic purposes. Indicator microorganisms are identified to demonstrate the presence of human and animal wastes and hence the potential presence of pathogens in drinking water (Yasin*et al*., 2015)

Table 01 – Coliform and *E.coli* counts of collected water samples

Type of bacteria	**S1**	**S2**	**S3**	**L**	**P1**	**P2**	**P3**	**SLS (614:2013)**	
								Pipe-borne water	**Well water**
Total number of all types of coliform bacteria present in 100 ml of the sample at 35 ± 0.5 ^{0}C	480	932	570	722	64	02	Nil	< 3	< 10
Number of *Escherichia coli* in 100 ml of sample at 44.5 ± 0.2 ^{0}C	172	600	200	213	02	Nil	Nil	Nil	Nil

In this study, the fully accepted and approved membrane filtration technique used in many countries as a procedure for monitoring microbial quality of drinking water, was used in the enumeration of coliform bacteria incollected water samples. Total coliforms and E.coli were detected using selective and differential culture media. Table 01depicts the numbers of coliform bacteria and *E.coli* in 100ml raw and purified water samples collected in the study. According to the WHO permissible limits, a zero count of *E. Coli* per 100 ml of water is considered safe for drinking. A count of 1–10 cells/100 ml is regarded as low risk and 11–100 cells/100 ml as medium risk. The *E. coli* count greater than100 cells/100 ml is considered as high risk. Raw water samples tested in this study revealed high numbers ofColiform and *E. coli* compared to raw water obtained from the stream connecting with Roseneath Lake in Dunumadalawa forest

(Daulagala et al.,2021).A high number of *E coli* recorded from the streams and reservoirs may be due to the addition of fecal matter from the animals, such as monkeys and deerthat visit these water sourcesto seekwater. After the coagulation and flocculation processes, very low level of coliforms were present in water, which was below the SLS permissible levels and, no detectable *E.coli* were present. The water discharges from the plant for the consumers were free of coliforms and*E.coli.*

Conclusion

Based on the physicochemical results, except for turbidity and pH of a few samples of raw and partially treated water, allof the investigated parameters of the remaining water samples were within the permissible limits of SLS and WHO guideline values for drinking water quality. Results of the bacteriological analysis revealed that all raw water samples contained very high numbers of both coliforms and *E. coli*and hence cannot be recommended for drinking purposes. But interestingly, all physicochemical and bacteriological parameters of the chlorinated water were within the permissible levels of SLS and WHO. Therefore, it can be concluded that the overall efficiency of theexisting treatment plant was ata satisfactory level. As a suggestion, a proper structure like a floating boom could be installedat the place where water enters the reservoir to prevententering the floatingdebris from the reservoir.The preservation of the catchment areas should also be given the top priority. It is recommended that frequent monitoring and proper technical maintenance of the existing treatment plant using skilledpersonnalare required for the assurance of providing potable water in good condition for the consumers who are relying on this water supply scheme.

References

Adebisi, O.O., Obuekwe, I.S., Akinsolu, F.T. &Olayemi, A.B. (2016). Evaluation of Escherichia coli as indicator of point-of-use chlorination efficiency of drinking water. *Journal of Applied Science and Environmental Management*, 20(4), 955-962.

Daulagala, P.W.H.K.P., Marasinghe, L.D.K. &Samithri, Y.A.S. (2021).Analysis of Physicochemical and Bacteriological Parameters of Raw and Treated Water of Roseneath Water

Purification Plant in Dunumadalawa Forest Reserve in Kandy, Sri Lanka. *Asian Journal of Research in Botany*,6(3), 42-50.

Dharmasena, C., Ekanayake, H., Abeysinghe, S. (2001).Dunumadalawa Forest Reserve. *Loris,* 22, (55-57).

Environmental Screening Report for the Augmentation of Dunumadalawa Water Treatment Plant, Strategic Cities Development Project, November 2015.

Joshi, T.P.,Koju, K.N.,Shrestha, M.S. &Raut, P. (2014). Drinking water quality of Kathmandu valley. *Nepal Journal ofScience and Technology*,15(1), 115-120.

Kim, E.J., Herrera, J.E., Huggins, D., Braam, J. &Koshowski, S.(2011) Effect of pH on the concentrations of lead and trace contaminants in drinking water: A combined batch, pipe loop and sentinel home study. *Water Research,*45, 2763–2774.

Yasin, M., Ketema, T. & Bacha, K. (2015).Physico-chemical and bacteriological quality of drinking water of different sources, Jimma zone, Southwest Ethiopia. *BMC Research Notes,*8, 541-554.

Olila,O.G., &Reddy, K.R.(1997).Influence of redox potential on phosphate-uptake by sediments in two sub-tropical eutrophic lakes. *Hydrobiologia*,345, 45–57.

Saad, B., Pok, F.W.,Sujari, A.N.A. &Saleh, M.I. (1998).Analysis of anions and cations in drinking water samples by Capillary Ion Analysis. *Food Chemistry,*61, 249-254.

Silva, E.I.L. (1999). Status of water quality in Sri Lanka. In: Recent trends in Environmental Biogeochemistry. V. Ittekot and V. Subramanian (eds.), *SCOPE publicaction*, Hamburg University, Hamnburg, Germany.

Sri Lankan Standards 614: Drinking water standard - First Revision. 2013.

WHO (World Health Organization). Guidelines for drinking water quality, 4rd ed. Recommendations, vol. 1. WHO Press, World Health Organization, Geneva, Switzerland. 2011.

Zabed, H., Suely, A., Faruq, G., &Sahu, J.N.(2014).Water quality assessment of an unusual ritual well in Bangladesh and impact of mass bathing on this quality. *Science of the Total Environment,*472, 363–369.