Assessment of water supply system from catchment to consumers: A study based on Rahas-Ella water purification plant in Kandy, Sri Lanka.

Abstract

Rahas-Ella is one of the fascinating waterfalls located in Wattegama area in Kandy District, Sri Lanka (7°21'11.00"N 80°41'39.99"E). By receiving raw water from Rahas-Ella, a water purification plant was established in 2013 with the intension of providing safe drinking water to the residents in Wattegama municipal area. Considering the complaints made by the consumers, a study was caried out to assess various physicochemical and bacteriological parameters to provide ambient water quality data of raw and purified water. Thirteen sampling locations (L1-L13) were identified along the waterfall, from the onsite water purification plant as well as wells and tap water sources through which the purified water is distributed. The study revealed that several parameters were higher than the standards concerned for drinking water. Mainly, the turbidity level was high in both catchment and the intake and this could be a serious health risks to the community. Further, considerably high total counts of both coliforms and *Escherichia coli* for all samples were detected, exceeding the standard values. Although oil and grease were not monitored in this present study, a number of dwellers reported problems associate with oil pollution. Based on the observations and results of the study, the following activities are recommended in order to improve the water quality of the catchment and to upgrade the treatment facility.

Key words: water quality, physicochemical parameters, microbiological analysis, Rahas-Ella fall.

1. Introduction

Water is essential in all aspects of life. However, the amount of fresh water available for human exploitation is finite and uneven. Therefore, access to safe water sources in terms of quality is of utmost importance. Anthropogenic activities are polluting the water resources, thus damaging the ecosystems, disturbing natural processes and posing a threat to the existence of all living beings [1]. Water quality of any specific area or specific source can be assessed using physical, chemical and biological parameters [2]. The values of these parameters are harmful to human health if they occurred more than the defined limits [3]. The drinking water purification plants are designed specifically to eliminate chemical and microbiological pollution in raw water through treatment stages in which harmful bacteria and other pathogens are eliminated from water.

Drinking water should meet specific standards and criteria for good public health and being free from disease-causing pathogenic microorganisms. Consumption of water polluted with pathogenic microorganisms can cause health problems in humans such as diarrhoea, cholera, typhoid, dysentery, and skin diseases [4]. Agriculture is one of the significant polluters of water bodies on a global scale [5]. and the use of chemical and organic fertilizers, growth stimulators and pesticides has increased the pollution in several folds during the last few decades [6].

Sri Lanka is an island in the Indian Ocean and has three climatic zones, the dry zone, with less than 1,900 mm of rainfall, the intermediate zone, with rainfall between 1,900 and 2,500 mm and the wet zone, with rainfall between 2,500 and 5,500 mm (Department of Census and Statistics, 1998). According to the available evidence, there is either little or no water scarcity in Sri Lanka. Even though there are certain dry zone places in the courtyards during the dry season to compete for the water. The statistics reveal that 78% of the population has access to drinking water from the nation's water supply. In this population, 35% has access to piped water and the remaining 46% are predicted to rely on alternate water sources such springs and bore wells [7]. Ground water resources are fairly good in most parts of the country but at present intensive irrigation practices and the over use of agrochemicals has caused deterioration of the quality of groundwater. Other than this, the tsunami severely affected groundwater specially in the coastal areas. Beside ground water resources, the country has about 225 springs out of which about 120 are located in the central highlands (Department of Census and Statistics, 1998). and many fascinating waterfalls. The State authorities have these water sources as well to serve people where the water supply from the national grid is not feasible. Most of these instances the local community has the responsibility of safe guarding the water source from anthropogenic pollution.

Waterfalls are one of the inland freshwater sources that receives very little attention of researchers worldwide. In Kandy district, Wattegama is one of the well-known towns having several waterfalls and they give an attractive natural beauty to the area. The Rahas-Ella project, which is currently well working, is one of three projects that make up the water supply system for the population of the Wattegama area. This water supply system provides water to a large number of connections in Wattegama area, including 1165 domestic and 360 commercial connections.

Even though Rahas-Ella waterfall preserves good quality water, some hotspots of pollution have lately been identified. Consumers claim that the quality of drinking water supplied by the purification plant is deteriorating over time. This may be either due to the high levels of domestic pollutants discharging to the fall, which cannot be eliminated through the purification process or due to the shortcomings of the existing purification process. Though Rahas-Ella fall is one of the significant sources of supplying drinking water to the consumers in Wattegama urban council, unfortunately, there is no information on the quality of water within the catchment. The research described in this paper was carried out to analyze the ambient water quality of the water fall with reference to the quality of water provides to consumers in the Wattegama area through the distribution network, using certain significant water quality parameters. In addition, prompt and significant remedies were addressed timely important solutions were provided to address the shortcomings of the existing purification plant.

2. Methods and Materials

Study area

Rahas-Ella is one of the fascinating waterfalls located in Wattegama area in Kandy District, Sri Lanka (7°21'11.00"N 80°41'39.99"E). This fall is about 15 m in height at the mean sea level and is formed by a stream starts from the Hunnasgiriya mountain range. This Rahas-Ella water supply system provides water to about 2297 connections in Wattegama, including 1165 domestic and 360 commercial connections. Wattegama area has a tropical monsoon climate having a considerable rainfall throughout the year (average annual rainfall is 1815 mm, the wettest and the driest months of a year are November and June respectively). The average annual temperature of the area is 24.6 °C.

Selection of sample sites and collection of water samples

Thirteen different sampling locations (L1-L13) were identified starting from the origin of the Rahas-Ella waterfall and from the onsite water purification plant, tap water sources distributing purified water from the plant and two wells in the area, one is shallow and the other is deep. (Figure 1).

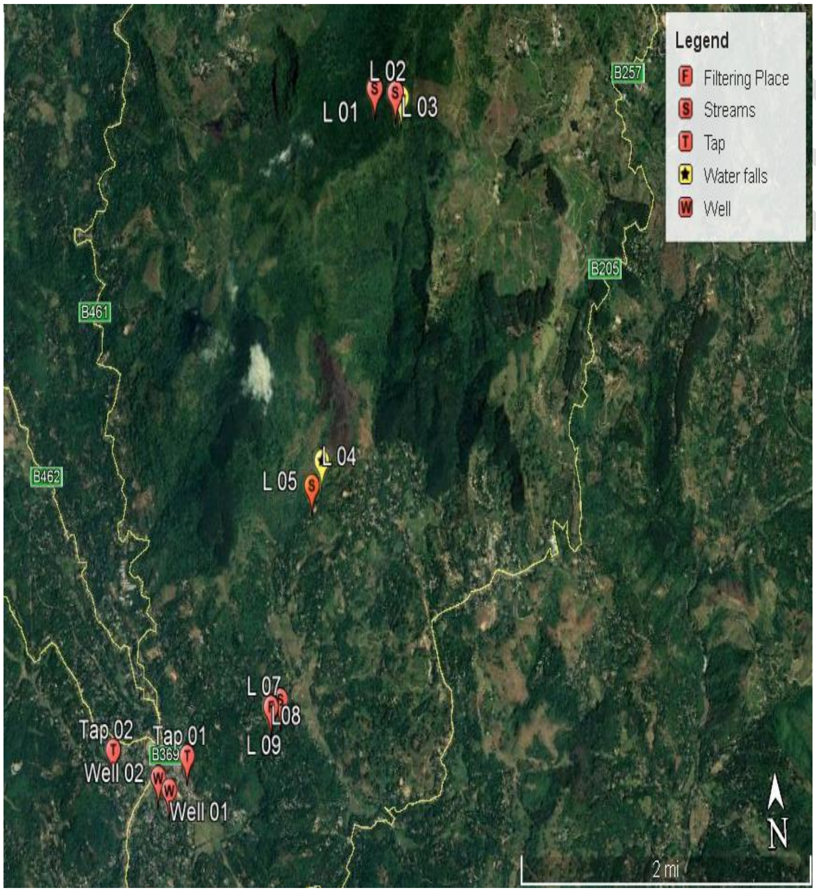

Figure 1- A Google earth map of the study area and the sampling locations

For laboratory analysis, a total of 39 water samples (in triplicates) from 13 sites were collected. Nine samples were taken from the waterfall and from the purification plant and two samples from shallow and deep hand-dug wells that the residents use for their drinking water. In order to determine whether there is a chance that purified water could become polluted throughout the distribution process, two samples from taps on Panwila Road and Pinnalanda Road were also taken for analysis. (Table 1). All samples were collected to cleaned and dry polystyrene bottles of 250 ml capacity during the morning hours in between 8.00 to 10.00 a.m. Before filling the samples, bottles were rinsed two to three times with the sample water in each location. For bacteriological analysis, water samples were collected in sterile bottles from the locations L6, L7 and L9 and delivered immediately to a microbiology laboratory. Samples were analyzed onsite and off-site for selected physical and chemical parameters such as pH, alkalinity, total hardness electrical conductivity and total dissolved solids. Temperature and pH were noted onsite while other parameters were analyzed in the laboratory.

Table 1: Description of the locations of collected water samples for analysis

Sample Location	**Coordinates**		**Description of location along the waterfall**
L1	7°23'30.00"N	80°42'18.01"E	A stagnant water filled pond close to the beginning of the stream
L2	7°23'29.00"N	80°42'25.01"E	Part of the stream in between the stagnant pond and the Duwili-Ella
L3	7°23'28.08"N	80°42'27.04"E	The starting point of Duwili-Ella falls (upper part of Rahas-Ella falls).
L4	7°22'7.57"N	80°41'57.17"E	The starting point of the Hunasgiri-Ella (middle part of the Rahas-Ella) surrounded by few mass rocks
L5	7° 22'1.79" N	80° 41'53.36" E	The shallow section of the stream. Residents use water for bathing and washing
L6	7° 21'11.00" N	80° 41'39.99" E	Water intake to the plant. The starting point of the Rahas-Ella falls.
L7	7°21'9.60"N	80°41'36.82"E	Sedimentation tank.
L8	7°21'9.54"N	80°41'36.56"E	Water after filtration

L9	7°21'9.48"N	80°41'36.51"E	Purified water after chlorination
L10	7°20'58.47"N	80°41'5.58"E	Tap 1 at a small village getting purified water from the plant
L11	7°21'0.99"N	80°40'38.83"E	Tap 2 at another small village getting purified water from the plant
L12	7°20'50.66"N	80°40'58.87"E	Deep well closer to the plant
L13	7°20'53.74"N	80°40'54.91"E	Shallow well closer to the plant

Analysis of water samples

Analysis of physicochemical parameters

The physicochemical parameters including pH, alkalinity, total hardness electrical conductivity and total dissolved solids (TDS) were analyzed. Temperature and pH were noted onsite while other parameters were analyzed in the laboratory after the samples were safely transported to the laboratory at National Institute of Fundamental Studies (NIFS), Hantana, Kandy.

The temperature and the pH of the samples was measured in the field (*in-situ*) using a thermometer and a pH meter (HANNA Instruments) while the electrical conductivity and the turbidity values of the samples was taken using an electrical conductivity meter (HANNA Instruments) and a turbidity meter (Thermo Instruments) respectively. Calibrated multi parameter was used to measure TDS and the alkalinity of samples were measured using potentiometric titration method with KEM autotitrator (AT-610-ST, Japan).

Analysis of Bacteriological parameters

As an entirely accepted and approved method for monitoring bacteriological quality of drinking water in many countries, the membrane filter (MF) technique was used in this study to enumerate the total coliforms and *E. coli* of few selected water samples.

Three water samples collected from L6, L7 and L9 locations of the waterfall and the purification process (Table 1) were subjected to the MF technique. The colonies grown on M- Endo medium at a temperature of 35 ^{0}C for 24 h of incubation for total coliforms and on an enriched lactose medium (m-FC) at a temperature of 44.5 ^{0}C for 24 h incubation for *E.coli* were counted.

3. Results and discussion

The study was conducted aiming the unsafe water quality issue which is one of the major problems in rural areas in Sri Lanka. Geographic Information System (GIS) technique was used for mapping the sampling locations and standard methods and calibrated equipment were used for testing water quality parameters. Physical, chemical and bacteriological water quality parameters were assessed in relation to the standards defined and recommended by the World Health Organization (WHO 2011) [8] and Sri Lanka Standards (SLS614:2013) [9].

Statistical analysis of physicochemical parameters

Turbidity

One of the most important factors in determining the quality of water is turbidity, which is the cloudiness of water brought by various particles. The findings of the turbidity of water samples collected from the locations L1 to L13 are shown in Figure 1. The maximum permissible level of turbidity (accepted) should be 5 NTU, while the maximum permissible level of turbidity (Drinking water) should be 2 NTU (SLS614:2013). No health-based guideline value has been proposed for turbidity by the WHO. However, the turbidity readings of the water samples taken from all thirteen locations ranged from 8 to 14.5 NTU, and all of the values were above the accepted and permissible limits.

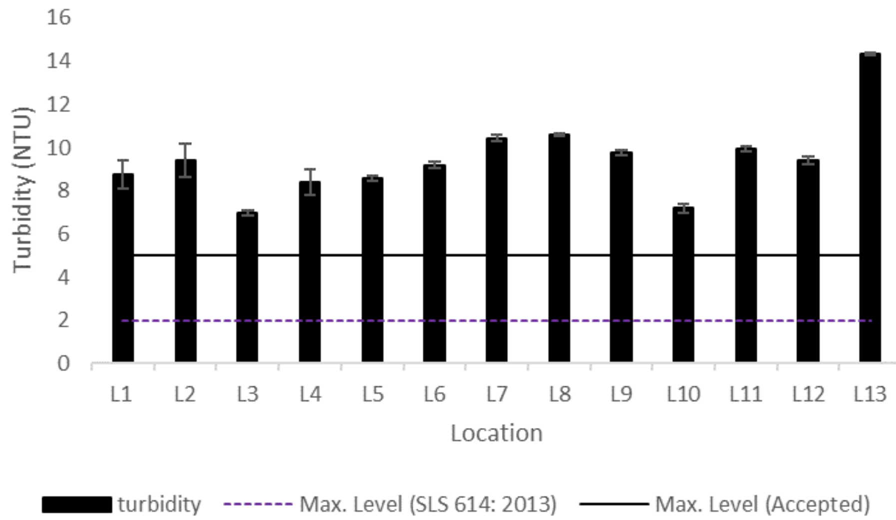

Figure 2. Turbidity of water samples collected from the locations L1 to L13

The water sample from sampling point L1 had a substantial amount of turbidity and contained algae. A significant growth of algae was seen in the sampling location L2 as well. The water from L3 and L4 was also turbid and strongly colored due to the presence of silt. Turbidity at sample point L6 and the rest (L6-L13) was much too high to be used as drinking water, with an average of 9.18 NTU. The average amount of turbidity in the water that release from the purification plant to the consumers (L9) was 9.75 NTU, which was well above the recommended level. This result showed that the current treatment plant is unable to efficiently handle excessive turbidity of water. The shallow well L13 has a turbidity rating of 14.5 NTU, which is unusually high. The well is exposed to the runoff from the paddy field that it shares a boundary with. There is a high probability that agricultural fertilizers will leak nutrients. However, it makes sense to assume that silt and enhanced algal growth are the main causes of excessive turbidity of L13.

Temperature

Drinking water temperature can significantly increase or decrease during the purification process and through the distribution system to the consumer. However, according to the data, the temperature of the water samples from all sampling points was within the range of 26 ^{0}C to 30 ^{0}C, and were therefore all above the WHO standard of 25 ^{0}C. These results imply that all samples had temperatures that were suitable for the development of a wide variety of algae, cyanobacteria and other microorganisms as particles in water. Presence of particles increases the turbidity of water. Turbidity is a measure of water clarity and high turbidity increases water temperature due to such particles absorbing sunlight. It was found that the turbidity of water samples showed a considerable consistency trend with the temperature of the water detected at the locations.

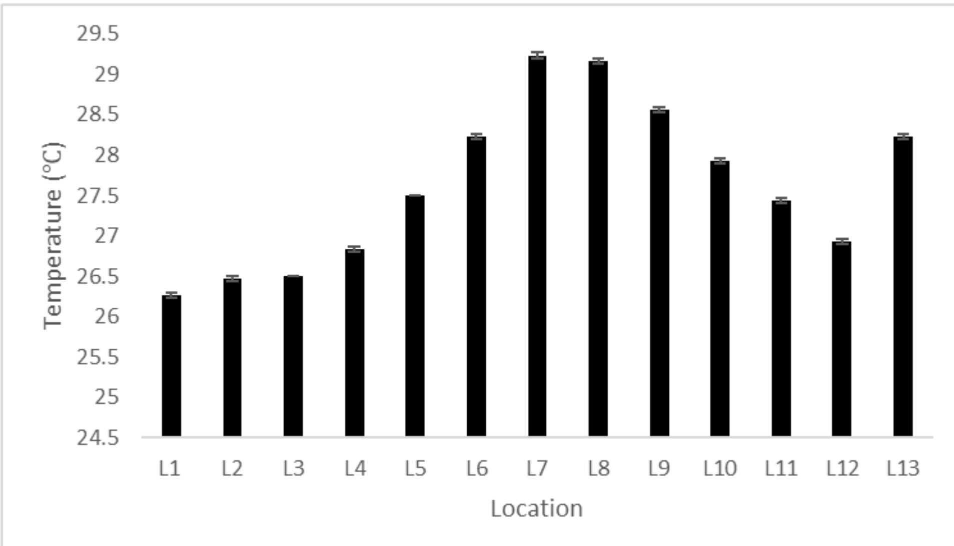

Figure 3. Temperature variations of water samples collected from the locations L1 to L13

Alkalinity

Low levels of alkalinity were found in the water at sample stations L1 to L5, and a significant rise in alkalinity was found at L6. (Figure 4) This high alkalinity level was maintained throughout the purification procedure and even slightly increased after chlorine was added to the water. The alkalinity of the samples taken from wells was somewhat decreased.

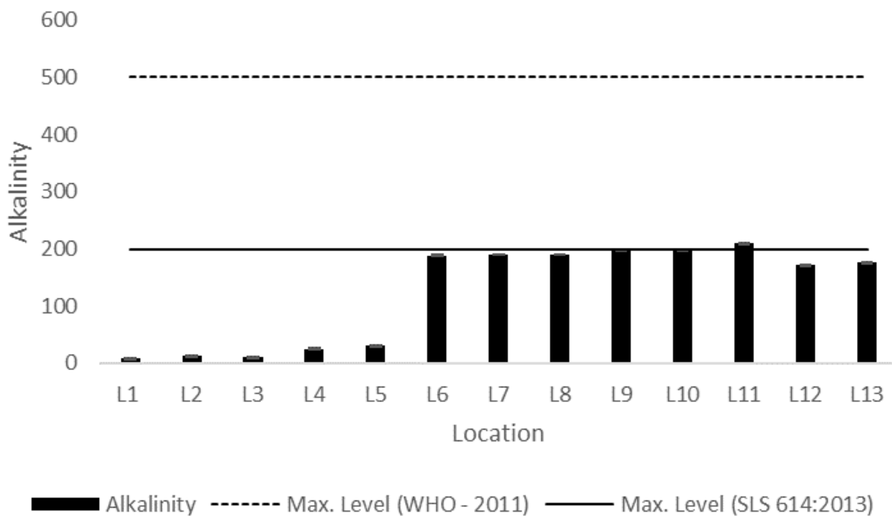

Figure 4 - Alkalinity of water samples collected from the locations L1 to L13

Alkalinity refers to the ability of the water to neutralize acids. Most of the water treatment processes reduce the alkalinity of raw water. However, in this study, samples of water from the intake and all the way up to the filtered water sent through the pipelines to consumers had high alkalinities. Alkaline water generally contains higher amount of total dissolved solids (TDS) which affects the pH levels of the water. The samples which had lower TDS values showed the pH less than 7 and were slightly acidic.

pH

pH is considered as one of the most important water quality parameters and the values are related to acidity or alkalinity of the water samples. It is noticed that water with low pH is tend to be toxic and with high degree of pH it is turned into bitter taste. According to the regulations of WHO (2011) and SLS (614:2013), the acceptable and safe pH range of drinking water is 6.5-8.5. The pH values of the collected water samples are found to be within the range between 5.9 -7.9. Out of thirteen, seven collection points had a pH lower than the neutrality. However, the samples taken from points L6 to L11 and L8, showed the pH higher than 7 and the pH observed from the samples collected at various stages of the purification process and the purified water distributed through the taps (L6 to L11) yielded the maximum pH of between 7.5 and 8.0. However, the pH value of the water distributed to the consumers was not exceeded the standard limits.

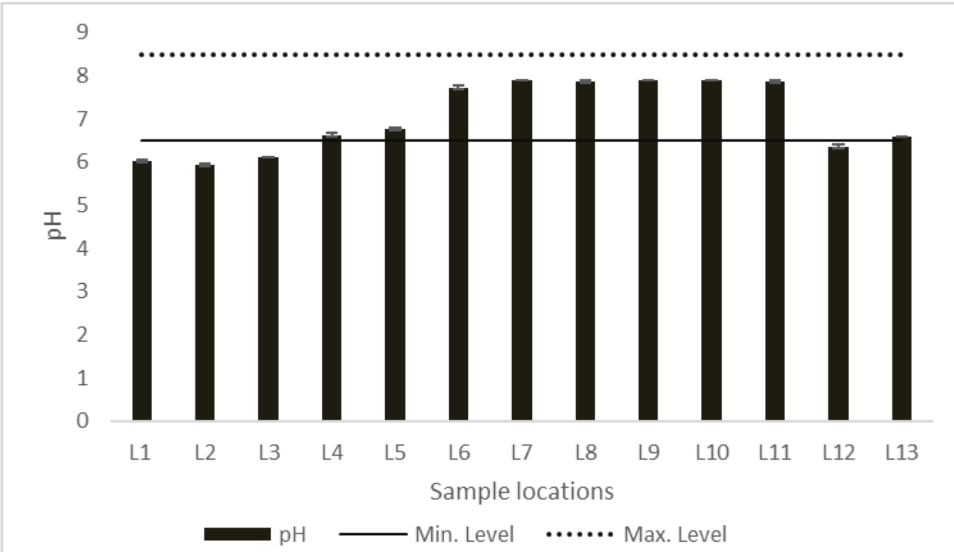

Figure 5 - Variation in pH of the water samples collected from the locations L1 to L13

Total dissolved solids (TDS)

The findings of this study (Fig. 5) demonstrate that the samples taken from the top portion of the canal (L1- L5) had low TDS values, however the location 6 had a greater TDS value and stayed more or less constant for the samples taken from L6 to L11. The sample collected from the shallow well (L13), which was next to a paddy field, had the greatest TDS value, while the deep well (L12), which was in a residential neighborhood, also had a significantly higher TDS value. However, none of the examined samples had TDS levels that exceeded the WHO limit of 600 mg/L water.

The catchment (L6) is subject to a number of human activities, and the TDS seemed to rise as the treatment operations progressed. As a result, the TDS level increased slightly after sampling point L6 but remained steady. The sample taken from the wells (L12 and L13) had greater TDS levels, which may have been caused by organic compounds and other ions dissolved in the well water.

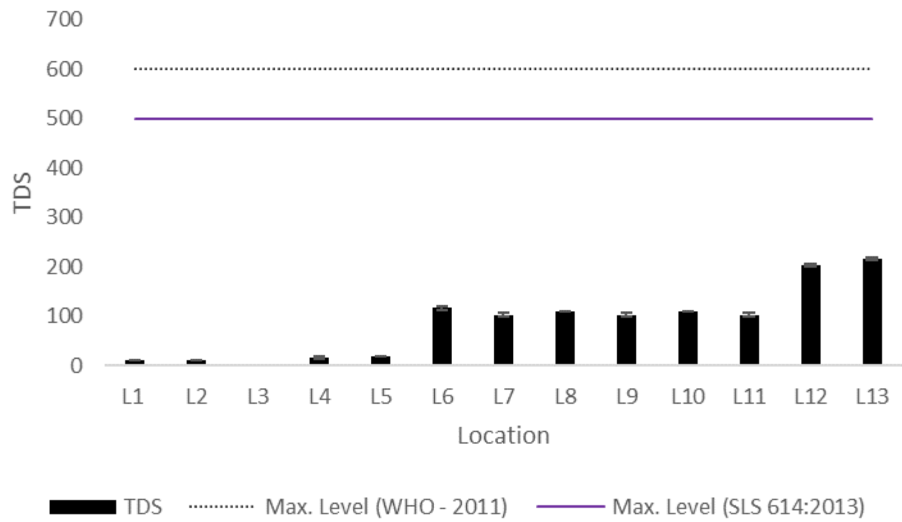

Figure 6 - Variation in total dissolved solids of the water samples collected from the locations L1 to L13

Electrical conductivity (EC)

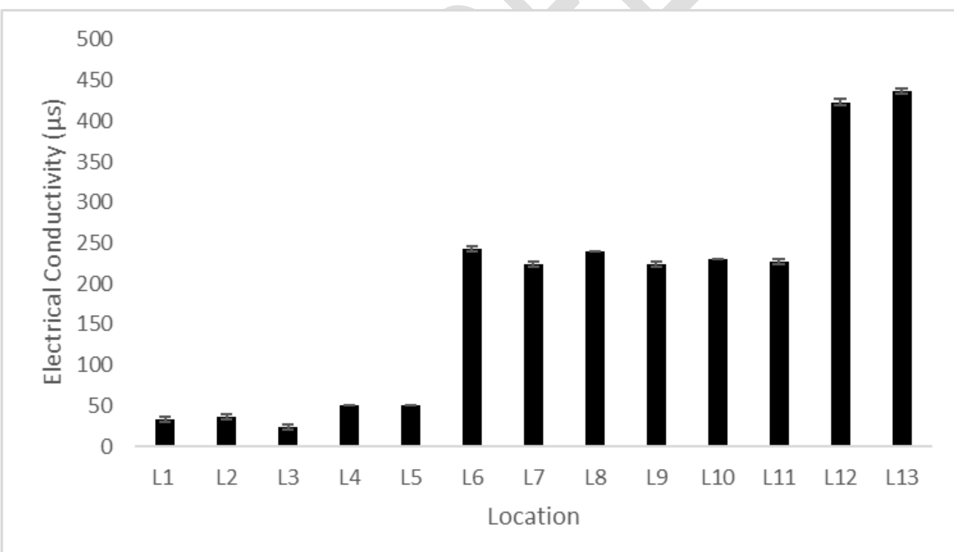

Figure 7 – Electrical conductivity of the water samples collected from the locations L1 to L13

According to the WHO guideline, the electrical conductivity of drinking water should not exceed 400 µS/cm. This present investigation indicated that EC value was 30 – 450 µS/cm with an average of 188 µS/cm (Fig. 6). The relationship between TDS and EC is a function of the type and nature of the dissolved cations and anions in the water.

Microbiological assessment of water for faecal contamination

The assessment of the microbiological quality of water from different sources is essential for detecting the presence or absence of microorganisms that might constitute health hazards in the water. These results could be used as a guide to monitor and protect the water sources. A majority of problems regarding the quality of community drinking water are related to faecal contamination by the bacterium *Escherichia coli*. *E. coli* is best suited as an indicator for faecal coliforms because there are fewer instances of encountering false positives [9].

Table.2: Description of three-points from where the water samples were collected for microbiological assessment

Sampling point	**Description of the point**
L6	The starting point of the Rahas-Ella falls. A Dam is built up to collect water used by residents for bathing and washing. Paddy fields in the surrounding area
L7	Sedimentation tank
L9	Purified water releasing out from the plant after chlorination

The results obtained revealed that all samples tested were positive for both total coliforms and *E. coli* (Table 3). The numbers of total coliforms and *E.coli* detected in the given water samples were exceedingly high as against the standard limits of WHO. However, the temperature readings recorded in these three locations were considerably high and this also may contribute to the high bacterial counts recorded.

Table 3: Total coliform and the *E-coli* count of the Water samples

Type of bacteria	**Results /100ml**			**WHO Standard**	
	L6	L7	L9	Pipe-borne water	Well water
Total number of all types of Coliform bacteria present in 100ml sample at 35 ± 0.5 ^{0}C	408	396	74	Nil	Nil
Number of *E. coli* in 100ml of sample at 44.5 ± 0.2 ^{0}C	194	188	32	Nil	Nil

The high coliform count obtained in the samples can be considered as an indication that the water samples collected from those points were somehow contaminated with faecal matter. Samples L6 and L9 were collected from points before the purification process starts, and there may be possibilities for entering sewage to the water as a result of some human activities. Additionally, the very high concentrations of coliforms in samples L6 and L7 may be the result of animals living in forest patches that may have been visiting to drink water and then discharging waste into the stream water. But unfortunately, the sample collected after the completion of the purification process (L9) also contained a massive number of coliforms as well as *E. coli*, compared with the standards. This result indicated the improper purification process of water which ultimately results as faecally contaminated water being distributed for human consumption.

4. Conclusions

Although the water from Rahas-Ella falls is treated, investigation of the samples collected from the catchment area, treatment process, and the consumer end outlets confirmed that the effectiveness of the water treatment plant is not satisfactory. The study evidenced that several parameters were higher than the WHO (2011) and SLS614:2013 standards for drinking water. Mainly, the turbidity level was high in both catchment and the intake. There could also be health risks to the community that use contaminated water for washing, cooking and other purposes.

Therefore, in order to lower the higher levels of pollutants, proper treatment procedures and management strategies are required.
However, the treatment plant is failing to reduce the turbidity and as a result, consumers are supplied water with high turbidity. In addition to being unattractive visually, excessive turbidity may indicate health problems. Although turbidity is not a direct indicator of health risk, it can promote regrowth of pathogens in water. When the presence of *E-coli* and the total coliform bacteria of the water samples collected before, during and after the purification process was enumerated, considerably high total counts for all samples were detected, exceeding the standard values. The primary sources of bacterial contamination might include the surface runoff, sewage entering the waterfall and improper management activities of the inhabitants like washing, refuse dumping and faecal droppings to the water source. Although, there is an apparent reduction of the total count of both *E-coli* and total coliforms after the treatment process, the counts are still exceeding the permissible level (0/100 mL) recommended for drinking water.

The attention for catchment conservation is almost neglected, although the pollution was high despite the presence of the treatment plant. Therefore, it is recommended to improve the catchment and improve water quality of the water intake. Strict actions should be taken about the entities which discharge polluted water to the catchment. Although oil and grease were not monitored presently, a number of dwellers reported problems associate with oil pollution. These pollution sources were identified, especially as agricultural activities, car wash and farms.

The technical awareness of the labourers regarding the maintenance of the treatment plant is not satisfactory and they require adequate technical training. Compilation of an operation and maintenance manual for the treatment facility is required. Water waste is commonly seen through the leaked pipe network. The well water can be easily mixed with the runoff and the nutrients which are leaching from the paddy fields as there are no protective mechanisms installed. Therefore, it is recommended to build walls for both wells and to plaster and seal. Further, it is required to block the runoff which enters directly and mixes with the well water. Dug wells should be regularly cleaned properly before using their water.

Based on the observations and results of the study, the following activities are recommended in order to improve the water quality of the catchment and to upgrade the treatment facility.

1. Conservation of catchment area.
2. Awareness of the local authorities regarding water quality issues
3. Upgrade the existing water treatment plant with expert assistance to control turbidity
4. Preparation of operation and maintenance manual for the treatment plant
5. Conduct community water safety programs

Ethics declarations

The authors declares that they have no conflicts of interest.

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