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RESEARCH ARTICLE

Spatial variation of harvested rainwater quality in South Vavuniya, Sri Lanka

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Abstract

Rainwater is one of the vital natural resources which plays crucial role in water cycle. Rainwater harvesting is a water conservation technique in which rainwater is captured and stored for various purposes. Despite being an excellent practice, rainwater harvesting does come with some challenges. As poor quality of harvested rainwater due to several natural and anthropogenic activities is one of such limitations, the current study was aimed to assess the water quality of harvested rainwater in Vavuniya south, Sri Lanka. For this study 189 samples were collected from Vavuniya south and the water quality parameters such as color, turbidity, coliform, E. coli, electrical conductivity (EC) and pH were analyzed. Further the recorded water quality data were mapped using ArcMap 10.8 software. Among the 189 water samples, 88% showed color below 1 Hazen while 12% showed color level above 1 Hazen. Notably, 7% of the samples exceeded a color value of 15 Hazen. Regarding the turbidity, 99% of the samples exhibited below 5 NTU. Out of the 189 water samples, 23% showed 0 Nos/100 mL coliform whereas 77% had coliform counts more than 3 Nos/100 mL. At the same time 57% of samples showed E. coli count lower than 10 Nos/100 mL among which 52% samples showed 0 Nos/100 mL numbers of E. coli. Among the 189 water samples, 43% samples showed E. coli numbers above 10 Nos/100 mL. Further, 95% samples showed EC below 200 µS/cm and 5% of the samples showed EC above 200 µS/cm. In addition, majority of the samples (80%) fell within the pH range of 6.5 to 8.5 while remaining 15% showed pH below 6.5 and 5% showed pH above 8.5. Based on the study, soil dust particles, fecal contamination, metal rooftops and emissions from development activities were found as possible causes for recorded poor harvested rainwater quality in some areas. Moreover, the samples analyzed from areas namely South Paravakkulam, Periya Ulukkulama, Avusathapittiya, Rangethgama, Kalukunnamaduva, Alagalla and Eratperiyakulama exceeded the standard range of water quality for at least two parameters. Therefore, regular maintenance and monitoring are required in these areas to ensure safe consumption of rainwater for various uses.

Keywords: E. coli, Electrical conductivity, Mapping, pH, Turbidity, Water conservation.

INTRODUCTION

Rainwater is the purest form of water however it may carry different disease causing microorganisms and chemicals before or after reaching the earth. Rainfall rate differs temporally and spatially. Despite being categorized as a country with either little or no water or moderate water scarcity, Sri Lanka may experience water shortage due to the ever growing population, limited water resources, and climate change (Vijitha et al., 2022). Even though access to clean water and sanitization at an affordable price is considered as one of the basic human rights (Langford et al., 2014), it is estimated that three billion of world population will suffer under water scarcity in 2025 (Hanjra and Qureshi, 2010). At this point, adoption of rainwater harvesting with proper management practices will enhance the efficient use of rainwater rather letting it to be wasted as runoff and help to increase food safety as well (Helmreich and Horn, 2009).

Sri Lankans have a long history of rainwater harvesting and the technique was further developed with the establishment of Lanka Rain Water Harvesting Forum which facilitates several rainwater harvesting projects all around Sri Lanka to promote usage of rain water for number of purposes including drinking (Vijitha et al., 2022). The sophisticated rainwater-cum-reservoir system of the Sigiriya, dating back to the 5th century, stands as a testament to this ancient tradition of rainwater harvesting in Sri Lanka (Ariyananda, 1999). In dry zone of Sri Lanka where water scarcity is one of the significant problems, rainwater harvesting would be a feasible technique to mitigate the issues related to water shortage (Yosef and Asmamaw, 2015). Adoption of Rainwater Harvesting Systems (RWHS) reduces monthly water bills which promote residents even in Colombo like cities to concern on construction of RWHS (Ranasingha and Wattage, 2024).

It is important to give equal consideration for both water quantity and quality. In that sense, as rainwater is free from contaminants it does not require prior treatments (Sturm et al., 2009). However, alteration in the quality during the processes likes water harvesting, storage, and household use (Khanal et al., 2020) would increase the resistance among public to use rain water considering related health issues. Several studies carried out in different places of Sri Lanka indicated that the quality of harvested rainwater must be taken into consideration before using it for various purposes including for drinking (de S Ariyabandu, 1999; Ariyananda, 1999; Rathnayake et al., 2020; Sayanthan et al., 2017). A study in Kebethigollewa, Sri Lanka focused on developing guidelines for rainwater harvesting systems showed that overhanging vegetation above the roof catchment is one of the reason behind the poor quality of harvested rainwater as those vegetation attract animals which causes entry of their excreta in to the RWHS. Furthermore, water quality analysis in the same study area revealed that fallen foliage blocking the gutters as one of the reason for slight acidification of harvested rainwater (Rathnayake et al., 2020).

According to the survey conducted in Anuradhapura district, Sri Lanka, non-functional first flush devices and filters lead to poor microbiological quality, with E. coli and total coliform counts which is exceeding the SLS 614:2013 standards (Ashanka et al., 2019). So, harvested rainwater, without extensive treatment, is not recommended for drinking but can be used for non-potable purposes (Sendanayake, 2016). Therefore, mapping of samples can be practiced as it enables spatial analysis, revealing correlations between water quality and geographical features such as proximity to industrial areas, agricultural lands, or natural water bodies. Moreover, maps effectively communicate findings to the public and stakeholders, making complex data more accessible and understandable areas (Wilde and Radtke, 1998). Therefore, the current study aimed to investigate the physical, chemical and biological qualities of rainwater collected from rainwater harvesting units in Vavuniya south, Sri Lanka by suing ArcGIS software.

MATERIALS AND METHODS

Methodology

From 531 rainwater harvesting units in the study area, 189 units were randomly selected from which harvested rainwater samples were collected for the current study. All the rainwater harvesting units were constructed under the project of farm foundation using plastic tanks with hard rock type of water filters and the water quality parameters such as color, turbidity, EC, pH, coliform and E. coli were analyzed at the regional laboratory of National Water Supply and Drainage Board (NWSDB), Vavuniya. All the 189 samples were collected from different 189 houses. Water samples were collected and analyzed according to the American guidelines. Then the measured values were compared with Sri Lanka standards institution specification of portable water (SLS 614: 2013). In addition, the recorded data were mapped using ArcMap 10.8 software.

Sample Collection and Handling

Glass bottles were washed with detergent after the usage. Then they were rinsed with washing acid (HNO3+HCl). Then bottle was washed again to remove the acid residues. Then again glassware was rinsed with distilled water. Then glassware was allowed to dry. Finally glass bottles were sterilized by using hot air oven at 170 ^{o}C for 45 minutes.

For coliform and E. coli testing, samples were collected in 500 mL sterilized glass bottles. To maintain sample integrity, the bottles with collected samples were stored in polystyrene boxes with ice packets. Immediately after the collection, those samples were transferred to the regional laboratory and, filtered and incubated for coliform and E. coli within 3 hours of collection.

For other water quality such as EC, turbidity, color and pH testing, samples were collected in 1500 mL clean plastic bottles. Then each sample was numbered and sealed. Immediately after the collection, those samples were transferred to the regional laboratory and water quality parameters were analyzed.

1. Measurement of pH

pH meter (HACH sensIONTM) was calibrated with pH 4.01, 7.00, and 10.01 buffers. Then the electrode was rinsed with deionized water and wiped with clean tissue. Then sample was taken into a clean beaker and Electrode was immersed in the sample. After that the pH button was pressed. When the reading is stable the pH was recorded and this procedure was repeated to each sample.

2. Measurement of electrical conductivity

The EC meter (HACH HQ14d) was calibrated by using calibration solution. After the calibration, probe was rinsed with deionized water and wiped with clean tissue. Then sample was collected into clean and dry beaker. After that probe was immersed into the water and EC button was pressed. Once the screen showed as "MEASURING BY STABILIZING" the EC was recorded.

3. Measurement of turbidity

For the turbidity measurement, the water samples were mixed well and 10 mL of sample was filled into clean sample cell. After closing the cap the cell was wiped with a soft lint-free cloth to remove water spots, water drops and fingerprints. Sample cell was inserted into the instrument cell compartment of turbidity meter (HACH 2100Q) and cap was closed. Power button was pressed to turn on the instrument. The RANGE button was pressed, and then the display showed AUTO RANGE. Finally turbidity was recorded.

4. Measurement of colour

Spectrophotometer (HACH DR 5000) was used to measure the color. For that the cells were washed with distilled water and wiped with soft lint-free cloth to remove water spots. Water samples were mixed well and 10 mL of sample was added into the each cell by using pipette. Then the spectrophotometer programme was changed to color testing. After that color index was calibrated to zero by using distilled water. Then each sample was placed one by one into the spectrophotometer and lid was closed. Finally color index was measured.

5. Coliform and E. coli counting

The water sample was filtered through a membrane filter with a pore diameter of 0.45 μm, which was preferred to bacterial filter. Next, the membrane filter paper was placed on the surface of the chromogenic coliform agar medium. Then petri dish was incubated for 18–24 hours at 37 °C. After 24 hours, the petri dish was removed, and the colony count was performed. The total coliform and E. coli count was determined by the salmon rose to red colonies and the deep blue to violet colonies. To calculate the concentration of coliform bacteria and E. coli in 100 mL, we used the volume of water filtered and the number of characteristic colonies counted on the membrane. The results were expressed as Colony Forming Units per milliliter (CFU/mL).

RESULTS AND DISCUSSION

All the maps employ a color gradient where darker shades indicate higher values while lighter shades indicate lower values of the sampled parameter. This visual technique helps to easily distinguish areas with higher concentrations or levels from those with lower ones. As the color darkens, it signifies an increase in the measured value, providing a clear and intuitive way to interpret the data distribution across the mapped area.

Colour and Turbidity

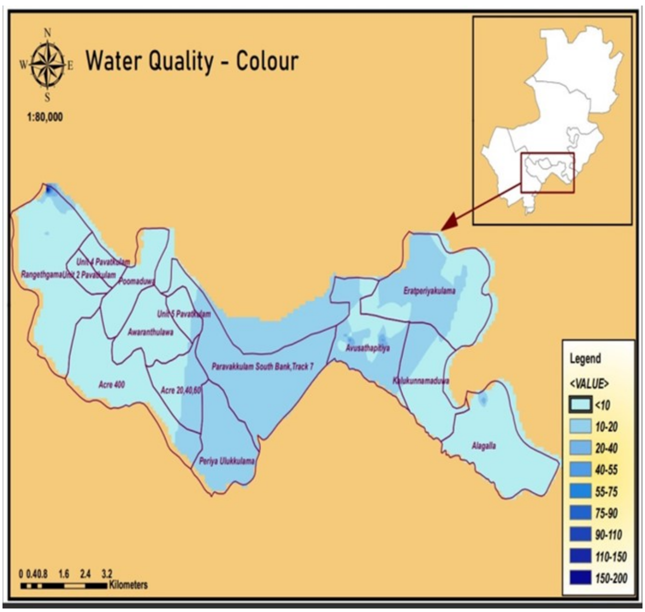

Figure 1. Color range of samples in the study area

Color is one of the good indicators to find the acceptation of water to drink. According to the figure 1 above, 88% of the samples showed the color below 1 Hazen, while 12% showed color levels above 1 Hazen. Notably, 7% of the samples exceeded a color value of 15 Hazen. Areas like Paravakkulam South, Periya Ulukkulama, Eratperiyakulama, Kalukunnamaduwa, Avusathapittiya, and Rangethgama north had a higher number of samples with color levels beyond the acceptable range.

The specific soil type of yellowish red hue present in these areas may contribute to dust particles that accumulate on rooftops. When rainwater washes over these rooftops, it carries the accumulated dust particles, potentially leading to the higher color observed in harvested rainwater. Islam et al., 2014 also indicated that dust accumulation on rooftops as one of the reasons for high range of color in harvested rainwater. Therefore, it is recommended to have first flush system. Roof-yard catchments with a "first flush" system provide the best quality water with low organic content. Self-purification during storage significantly improves rainwater quality (Zhu et al., 2004).

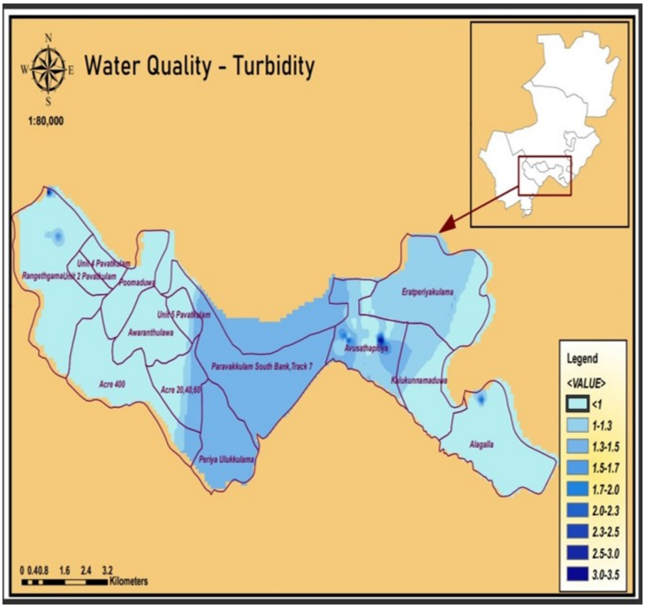

Figure 2. Turbidity range of samples in the study area

As shown in the figure 2, 99% of the total samples exhibited turbidity levels below 5 NTU, while only 1% had turbidity above 5 NTU. Notably, areas like Paravakkulam South, Periya Ulukkulama, Avusathapittiya, Eratperiyakulama, Kalukunnamaduwa and Rangethgama North showed a higher number of samples with high turbidity range.

Similar for the color, presence of red soil dust particles on rooftops might have contributed to the elevated turbidity levels. When rainwater washes over these rooftops, it carries the accumulated dust particles, which may explain the observed high turbidity in harvested rainwater. Suspended particulates from soil, debris, and microorganisms increase turbidity, impart color, and interfere with light penetration. These particles vary in size and density, affecting their settling velocities. Techniques like erosion control, sedimentation, and filtration can be recommended in these places to manage turbidity (Boyd and Boyd, 2020). A recent study by Dao et al., 2021 and indicated that cleaning the reservoirs significantly impact the levels of dissolved solids. Additionally, usage of strainers and frequent cleaning of catchment roofs and gutters were found to reduce water turbidity. Further, first flush filtration is a good way to remove unwanted particulates from roof top (Zhu et al., 2004).

Coliform and E. coli Bacteria

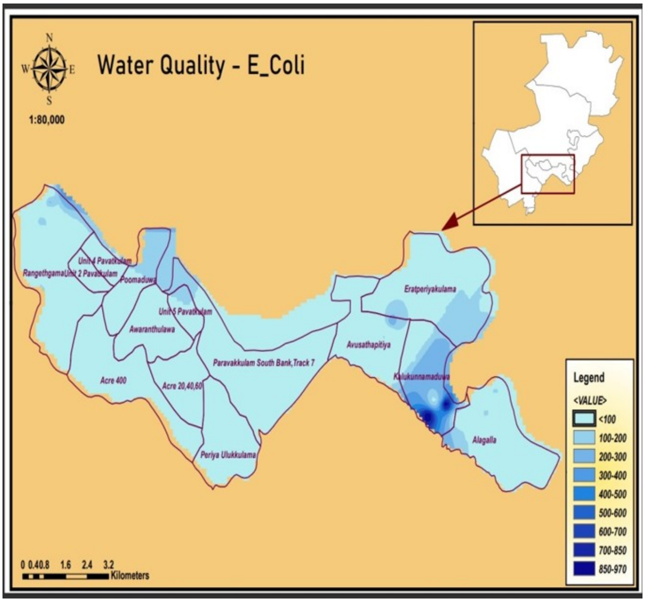

Figure 3. E. coli range of samples in the study area

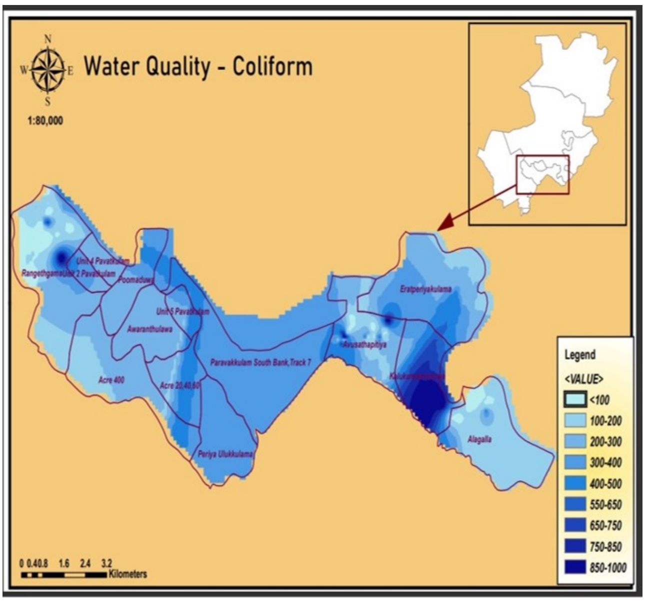

Figure 4. Coliform range of samples in the study area

Based on the figure 3, 0 Nos/100 mL coliform counts was recorded in 23% of the samples while 77% had coliform counts exceeding 3 Nos/100 mL. Among the areas where the presence of coliform observed, the Alagalla area stood out with slightly lower coliform counts whereas most of the other locations exhibited coliform levels above the acceptable range. As illustrated in the figure 4, among the 189 sample studied, 57% of the samples showed E. coli count lesser than 10 Nos/100 mL of which 52% showed 0 Nos/100 mL number of E. coli. However 43% of samples showed E. coli number above 10 Nos/100 mL. Especially, Kalukunnamaduva, Eratperiyakulama, Pavatkulam unit 5, Poomaduva, Alagalla and Rangethgama exhibited higher E. coli levels. As these villages are concentrated with trees, these areas remain habitat for high number of monkeys. So, wash out of monkey fecal from roof tops rainwater may be the reason for the presents of coliform and E. coli in collected water.

According to Sazakli et al., 2007, microbial pathogens can originate from fecal contamination by birds, mammals, and reptiles that access catchment areas or water storage tanks. Most coliforms are abundant in the intestinal flora of humans and other warm-blooded animals, and are therefore found in fecal waste (Rompre et al., 2002). E. coli serves as an indicator of fecal contamination, which can pose health risks. Therefore, complete absence of E. coli bacteria is crucial for safe drinking water. Fecal is one of the most important sources of coliform and E. coli in water. Fecal materials of animals and birds act as possible reason for the occurrence of coliform and E. coli in water (Jamieson et al., 2003). First-flush diversion, filtration, and disinfection being essential to get good quality rainwater (Mendez et al., 2011) and also Cleanliness of rainwater harvesting unit will help to reduce microbial contamination in harvested rainwater (Khanal et al., 2020).

Electrical Conductivity

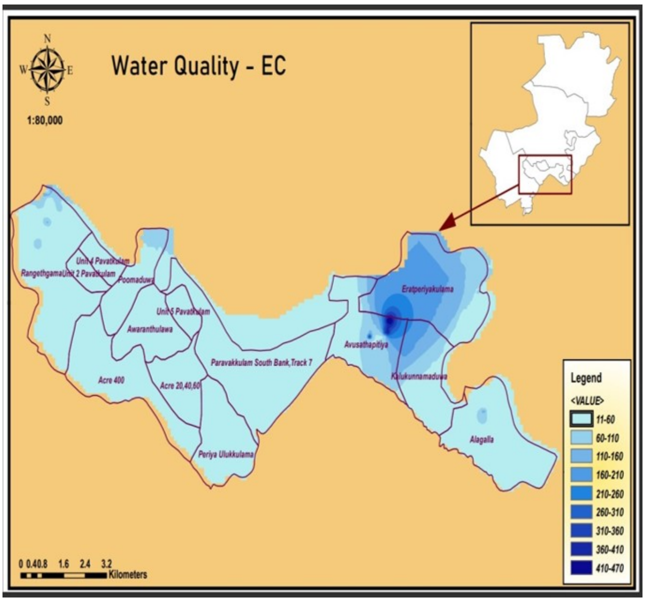

Figure 5. Electrical Conductivity

Figure 5 above illustrates the electrical conductivity of harvested rainwater in Vavuniya south where 95% of the samples showed EC below 200 μS/cm of and 5% of the samples have EC above 200 μS/cm. Presence of dirt in roof tops and tanks, hard rock filters would have contributed for high EC. It may occur due to the airborne particles, irons and other salt particles released from different types of roof tops (Al-Fahal et al., 2024). Decomposition of organic matters can release acids and irons while washout of these particles with rainwater may cause high EC in harvested rainwater (Sarwar et al., 2008). Areas with high EC values, such as Avusathapittiya and Eratperiyakulama, consists significant concentration of trees. However, due to ongoing development projects, these regions are transforming into urban areas. Unfortunately, this development may lead to increased emission of dust particle in the surrounding environment. Based on the findings of Sazakli et al., 2007, chemical contamination of rainwater can occur due to traffic emissions and industrial pollution in urban areas, or from the use of fertilizers and pesticides in agricultural regions. So, it may affect the electrical conductivity of the harvesting rainwater. Gross pre-tank filters catch large dirt particles like leaves, moss and first-flush device, which is used to discards the initial volume of roof runoff helps to remove most pollutants from the roof surface (Sánchez et al., 2015). Using these kinds of device and filter systems help to prevent contamination of rainwater from impurities.

pH

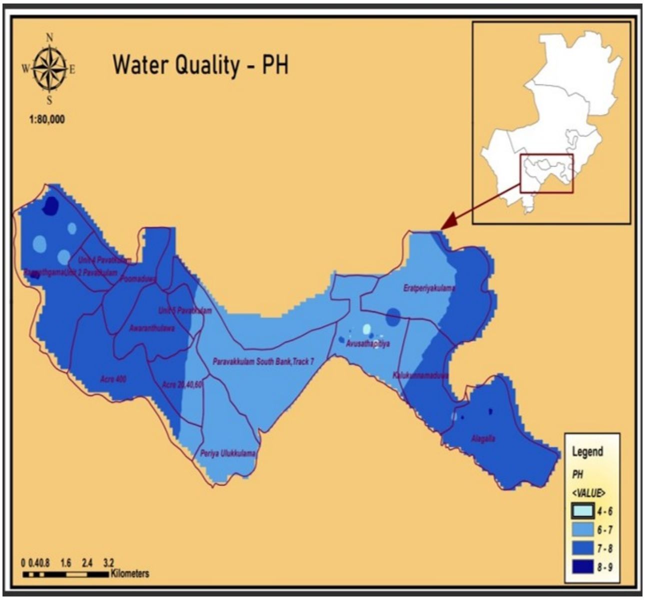

Figure 6. pH range of samples in the study area

Majority of the samples (80%) fell within the pH range of 6.5 to 8.5 while remaining 15% exhibited a pH below 6.5 and 5% showed a pH above 8.5. The Notably, Paravakkulam south and Periya Ulukkulama showed better pH values than other areas. Olaoye and Olaniyan, 2012 reported an existence of correlation between the pH of harvested rainwater and the type of rooftop material used. In detail, concrete rooftop leads to comparatively higher pH than metal rooftop in harvested rainwater (Thomas and Greene, 1993). Roofing material is a crucial factor in designing rainwater catchment systems (Mendez et al., 2011). Variation in pH values recorded in the current study also might be due to the different roof materials being used by the beneficiaries in the study area. As calcium carbonate dissolves, it increases overall water alkalinity. Therefore, use of hard rock water filters in this rainwater harvesting project would have contributed to the alkalinity of the water (Sallanko et al., 2003). So Instead of using hard rock filters, usage of Nano and dual media filters will help to remove impurities from water without affecting water quality parameters. Using Nano filters is a good way to improve water quality (Mohammed et al., 2007). The dual media filtration system was found to be more effective for reducing the pH of water (Laghari et al., 2018).

CONCLUSIONS

Based on the study, harvested rainwater samples in some areas showed color and turbidity levels beyond the acceptable ranges due to the presence of red soil dust particles on rooftops. The combination of high color and turbidity levels suggests that it is essential to practice regular cleaning of rooftops and proper filtration methods to mitigate these issues. Further, areas with high count of coliform and E. coli should adapt special strategies to reduce fecal contamination especially from animals and birds. As high EC content in areas like Avusathapittiya and Eratperiyakulama is predicted due to ongoing urban development, it is necessary to check the extend of its influence on harvested rainwater quality. Furthermore, extreme pH values recorded in few villages because of the different type rooftops and hard rock filters. It requires selection of appropriate rooftop and filter material to ensure the quality of harvested rainwater. Overall, the samples analyzed from areas namely Paravakkulam South, Periya Ulukkulama, Avusathapittiya, Kalukunnamaduva, Rangethgama, Alagalla and Eratperiyakulama exceeded the standard range of water quality for at least two parameters. Therefore, regular maintenance and monitoring are required in these areas to ensure safe consumption of rainwater for drinking purpose.

Author contributions

Jeevaraththinam Lajeeka: Conceptualization, writing draft, writing review, formal analysis and editing; S. Saravana, V. Vijitha, J. Vijayabalan: Data curation.

Conflict of Interest

There is no conflict of interest in this study.

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Data availability

Data related to the findings of this study are available at the corresponding author.

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