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## Research Paper

# Reusable rainwater quality at the Ikorodu area of Lagos, Nigeria: impact of first-flush and household treatment techniques

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## ABSTRACT

Water scarcity is a huge problem in Africa, and hence rainwater becomes a crucial water source for fulfilling basic human needs. However, less attention has been given by African countries to the effectiveness of common rainwater treatments to ensure the population's health. This study investigates the impact of different household treatment techniques (HHTTs), i.e. treatments by chlorine, boiling, alum, and a combination of alum and chlorine, on its storage system using a case study at the Ikorodu area of Lagos state, which is a rural area in Nigeria. The first-flush quality has been particularly studied here, where the microbial reduction through its practice has been examined from five different roofs. One of the investigated roofs was from a residential building, and four were constructed for the purpose of this study. In this study, the physical parameters (i.e. total suspended solids and turbidity) and the microbial parameters (i.e. total coliform and *Escherichia coli*) of the collected rainwater have been investigated. From the results, it has been observed that: (1) the water quality at the free phase zone is better than that at the tank's bottom; (2) the combination of chlorine and alum gives the best rainwater quality after comparing the application of different HHTTs; and (3) a reduction of about 40% from the original contaminant load occurs in every 1 mm diversion.

**Key words:** *Escherichia coli*, roof-harvested rainwater (RHRW), total coliform, total suspended solids (TSS), turbidity

## HIGHLIGHTS

- Different household treatment techniques on rainwater have been studied.
- The case study at the Ikorodu area of Lagos state, Nigeria, has been chosen.
- First-flush impact on microbial reduction has been examined on five types of roofs.

## 1. INTRODUCTION

The shortage of safe drinking water is one of the numerous significant issues that are experienced in the economically less-developed countries in the world. As the world's population and water demand increasing over the last few decades, the literature has shown that water scarcity in those countries has become a major challenge (Kaldellis & Kondili 2007; WHO/UNICEF 2019). The impact of increasing sediments and pollutants in natural water resources and rivers with complex terrain also further devastates the existing drinking water sources as studied numerically and experimentally (Pu 2016, 2021; Pu *et al.* 2016, 2017). The utilisation of harvested rainwater has the propensity to alleviate the continuing shortage of water, where several studies have considered it as a response to obtain drinkable water (Moruzzi & Nakada 2015).

The major issue with respect to the use of roof-harvested rainwater (RHRW) is the presence of contaminants (e.g. physico-chemical contaminants or microbiological pathogens) from the environment. Two major sources of external contamination have been identified by various researchers to be the atmospheric environments during the harvesting of rainwater and the impact of age and cleanliness of the storage tanks, gutters, roof catchments and pipes (Yaziz *et al.* 1989; Lee *et al.* 2012).

The quality of rainwater from different roof materials has also been assessed by previous studies (Yaziz *et al.* 1989; Uba & Aghogho 2000). In the study conducted by Uba & Aghogho (2000) to investigate the quality of rainwater from different roof catchments (i.e. corrugated galvanised iron sheet, aluminium, asbestos and thatch roofing materials) in the Port Harcourt district of Rivers state Nigeria, their results showed that the corrugated galvanised sheet gave better-harvested rainwater quality. Besides, its quality was also attributed to the ability of the roofing material to store heat from high temperature and ultraviolet light.

One of this study's objectives is to assess the impact of first-flush on different roof materials in the investigated area. First-flush is a process of diverting rainwater before it is collected and stored. The study from Gikas & Tsihrantzis (2012) demonstrated that the first-flush system improved the physicochemical quality of collected rainwater, but it could not prevent microbial contamination. Amin *et al.* (2013) further concluded that there was an improvement in the rainwater quality after diverting 1 mm of the rainwater, but their outcome still showed harvested rainwater contamination after diversion. Another study by Martinson & Thomas (2005) showed that 40% of the contaminants were diverted after every 1 mm diversion of the rainwater. To have a more detailed investigation to fill the research gap, this study diverted successive 0.5 mm before the water samples were collected for analysis.

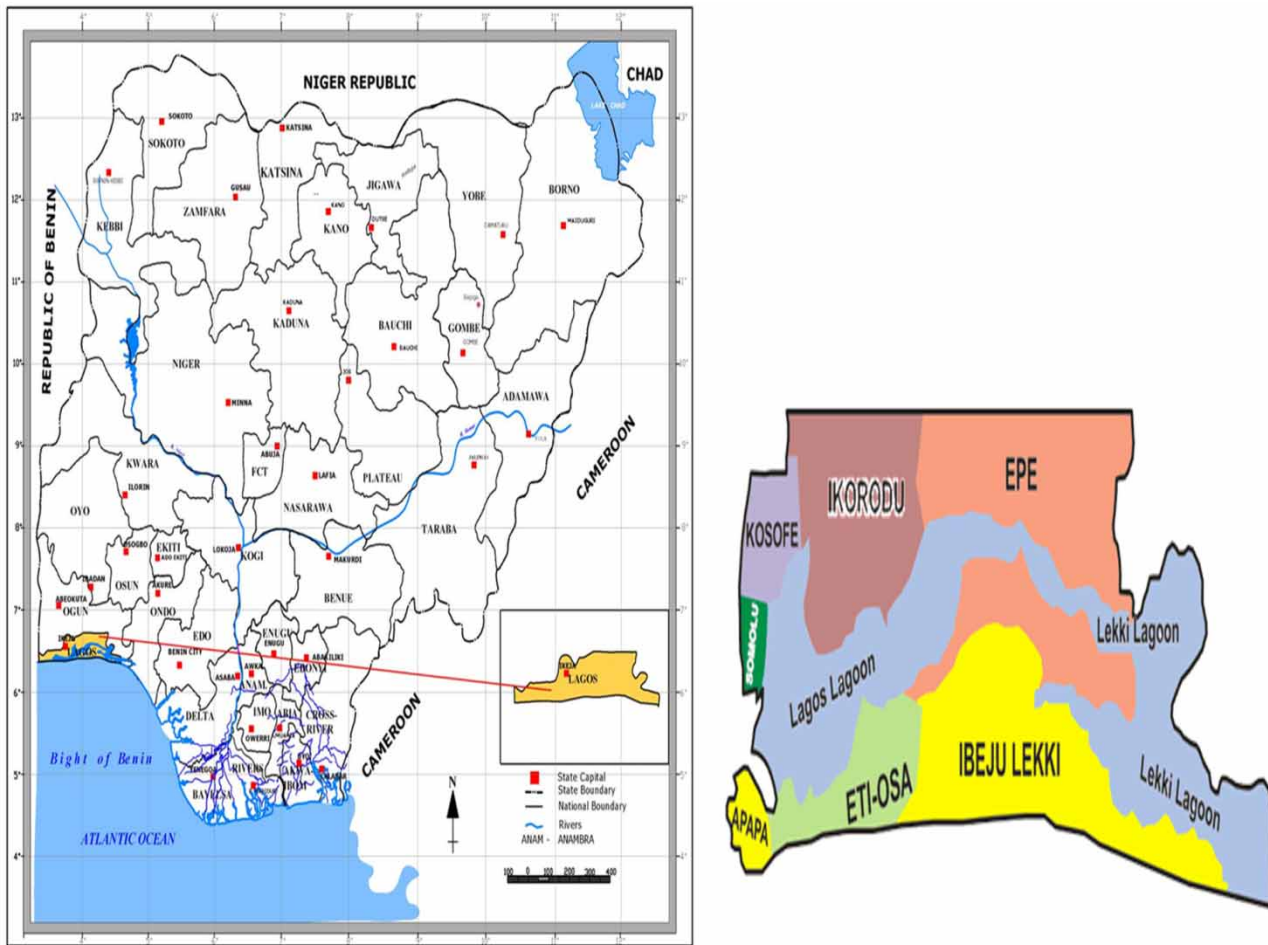
Beside the above-mentioned, the importance of different household treatment techniques (HHTTs) has been described by several studies, and they include boiling, chlorination, alum, solar disinfection and UV light lamp (Cotruvo & Sobsey 2006; Clasen *et al.* 2014). Each technique has its own merits and limitations. The boiling technique is primarily used in rural areas that are economically less developed. It is frequently used as other more refined techniques of disinfection are not always available in Africa's rural areas (Clasen *et al.* 2014). Boiling was the key approach used to kill pathogenic microbes before the emergence of chlorination (Clasen *et al.* 2014; Geremew & Damtew 2020). When chlorine is applied in the right amount, it can be an effective disinfectant; however, its use can raise safety issues (Clasen *et al.* 2014). In addition, chlorine is very reactive and can interact with other substances, such as metals, ammonia and hydrogen sulphides, that exist in the water. For another HHTT, the application of alum in rainwater can enhance the particle separation process within water. The resulting coagulation from alum promotes flocs growth, after which treatment can be performed by sedimentation, filtration, flotation or any other separation process. The flocs growth is dependent on alum dosage, pH and mixing condition. Studies have shown that the optimal pH range for alum coagulation is about 5.5–7 (Yang *et al.* 2010; Hussain *et al.* 2014).

Due to the importance of HHTTs, this study investigates the impact of chlorine, boiling, alum and the combination of alum and chlorine to RHRW collected at the Ikorodu area of Lagos state, Nigeria. The impact of adding alum into the rainwater storage tank was investigated as a comparative factor, since it functions only as a coagulant. The microbial level in the rainwater storage tank was inspected alongside specific practices of water quality improvement, such as first-flush and HHTTs, to determine their effectiveness. For this investigation, the collected rainwater was analysed for both physical (i.e. total suspended solids (TSS) and turbidity) and microbial parameters (i.e. total coliform and *Escherichia coli*), and the results were compared against the WHO guideline limits to ascertain whether it is usable and consumable.

Lastly, preliminary studies conducted by John *et al.* (2021b, 2021c) to assess the health risk of consuming RHRW in the same area at Lagos concluded that 25% of interrogated respondents claimed to harvest and drink RHRW, while over 90% claimed to harvest and use it for other purposes. Therefore, this study's pilot investigation of the impact of first-flush on RHRW in the Ikorodu area is imperative and practical, as people depend on the rainwater for their daily needs. The study is not only important to the residents of Ikorodu but to everyone who harvests and uses rainwater in the developing countries.

## 2. DESCRIPTION OF THE STUDY AREA

Nigeria has an enormous land area estimated at 923,770 km<sup>2</sup> and is bordered on the north with the Republic of Niger and Chad, on the south with the Atlantic Ocean, on the west with the Republic of Benin and on the east with the Republic of Cameroon (Figure 1). The climate of Nigeria varies from equatorial in the south to tropical in the centre, and arid in the north. Nigeria's climate heavily influences the quantity of the country's water resources. Its climate is mainly impacted by two main seasonal systems: the hot, dry and dusty wind which drifts from the northeast over the Sahara Desert; and the relatively cool and moist monsoon wind which comes from the southwest over the Atlantic Ocean. Annual rainfall in Nigeria vastly varies from 250 mm in the north to over 4,000 mm in the south, with a national average of 1,180 mm. Rainfall in Nigeria is seasonal, with the rainy season occurring between April and September/October, and the dry season occurring from November to March. The annual mean temperature ranges between 26 and 31 °C (Carter & Alhassan 1998).



**Figure 1** | Map of Nigeria showing Lagos state and the cross-sectional map of Lagos state showing the location of Ikorodu (Source: Longe *et al.* 2010).

The study area is located at the Ikorodu Local Government Area within Lagos (Figure 1). Ikorodu is a city which shares a boundary with Ogun State. This area was chosen because it is one of the fastest developing areas in Lagos which is known for its high utilisation of rainwater harvesting (Longe *et al.* 2010). The main sources of drinking water in Nigeria are surface water (such as streams, lakes, rivers and estuaries), pipe-borne water, boreholes, dams, man-dug wells and rainwater harvesting (Longe *et al.* 2010). It was assessed that an annual 224 billion m<sup>3</sup> of water can be collected from runoff in Nigeria. It was also estimated that about 96-million Nigerians (48% of the population) use surface water for their domestic needs, while 20% of the population (about 40-million) depend on harvested rainwater for their needs (Longe *et al.* 2010; John *et al.* 2021a). It is therefore crucial that the rainwater harvested is safe for usage.

### 3. MATERIALS AND METHODS

#### 3.1. First-flush technique

The experiments have been utilised to determine the improvement on both physical and microbial qualities through the practice of first-flush from five roofs, where one of the roofs utilised was from a residential building and four others were carefully constructed for the purpose of this study. The four roofs were built using different materials, i.e. asbestos, aluminium, corrugated galvanised iron and plastic sheets. Compared to the newly constructed roofs, the residential roof was over 15 years old and built with asbestos. In each experiment, the water sample was collected six successive times after an interval of 0.5 mm of rainfall resulting in a total of 3 mm.

### 3.1.1. Experimental method for residential building and four constructed roofs

Guidelines suggested by Yaziz *et al.* (1989) and Martinson & Thomas (2005) were used for the collection process of first-flush water. A 1 L new plastic bottle, prewashed with sterilised water, was used to collect the harvested rainwater sample at different periods of the rainfall event. It was ensured that a minimum of three dry antecedent days passed before harvesting rainwater for analysis in order to ascertain realistic accumulation of particulate matter before measurement (as suggested by Martinson & Thomas 2005; Doyle 2006).

The precipitation of rain was measured using a rain gauge. The rain gauge was also washed with sterilised water before it was placed in an open place (without obstruction from trees, houses or other buildings) to collect rainwater, and this was repeated after each rainfall measurement. A minimum of 4 mm rainfall was recorded by the rain gauge for each analysed rainfall event, and this was done to enable the completion of the six successive analyses of rainwater.

### 3.2. Impact of household water treatment techniques

Rainwater was collected directly into a 255 L tank via a 2.5 m gutter, and 5 L of the water sample was collected from the top of the tank on cessation of the rainfall event. This top level was selected because the residents take water from the top of the tank via cups or jug and do not store the harvested rainwater for a long period. The 5 L of the water sample was divided into five equal parts for different experiments. The storage tank and water sample containers were washed with sterilised water before the harvest of each analysed rain event. The result from the microbial analysis of the sterilised water showed no detected total coliform and *E. coli*. This was done to ascertain that the storage tanks were bacteria-free before the harvest of each rainfall. Four rainfall events were harvested and analysed for the HHTT experiments. Two of them were conducted in the dry season, while the remaining two were performed in the rainy season. The HHTTs considered in this study have been discussed as follows:

*Boiling*: In this technique, 1 L rainwater was boiled for 10 min to 100 °C (Spinks *et al.* 2006). The physical and microbial parameters were measured before and after the boiling.

*Alum*: Alum is added into the water to enhance the particle separation process. As it is not a standalone treatment, the processes of sedimentation and filtration are employed to purify the treated water. 18 g of the powdered alum was weighed, mixed and dissolved into a 1 L raw water sample (as instructed by the manufacturer's guidelines). Rapid (110 rpm) and slow (40 rpm) mixing was applied for 3 and 25 min, respectively, and the water sample was then allowed to settle for 1 h (Cotruvo & Sobsey 2006). After that, the water sample was analysed for *E. coli*, total coliform, turbidity and TSS.

*Chlorination*: Sodium hypochlorite was used as a source of chlorine here. In its application, 15 g of powdered sodium hypochlorite was weighed and dissolved into 1 L sampled rainwater (as advised by the manufacturer's guidelines) before the physical and microbial parameters were analysed.

*Chlorination Combined with Alum*: A combination of alum and sodium hypochlorite was used. 15 g of powdered sodium hypochlorite and 18 g of the powdered alum were weighed and dissolved in a 1 L rainwater sample. Rapid and slow mixing took place before the water sample was allowed to settle for 1 h. The process of measuring the physical and microbial parameters took place after the settling period.

### 3.3. TSS and turbidity

The TSS were determined using the vacuum filtration device, and the turbidity was examined using Hanna Turbidimeter. The steps used to determine TSS and turbidity in the water samples are as described by the standard methods in APHA, AWWA & WEF (2005). All tests were done in duplicates.

### 3.4. Colilert-18 method

The *E. coli* and total coliform concentrations were enumerated using the standard Colilert procedure (IDEXX, Westbrook, ME, USA). The Colilert technique was executed in accordance with the manufacturer's guidelines. This method has been employed in various studies, including Julian *et al.* (2015) and Martin & Gentry (2016). All microbial testing within this research was done in duplicates.



## 4. RESULTS AND DISCUSSION

### 4.1. Results and discussion on first-flush

#### 4.1.1. Water quality analysis from the roof of the residential building

**4.1.1.1. Physical parameter.** The characteristics of the harvested rainfall events are presented in [Table 1](#). This section also presents the analysis of the percentage reduction in the physical parameters for all five inspected rainfall events. The result showed that the turbidity and TSS values of RHRW are higher than the harvested free fall rainwater (FFRW). The higher turbidity and TSS values were caused by the deposition of dust/particulate matters and animal/bird faeces on the roof, especially after a long period of dry antecedent days. According to [Lee et al. \(2012\)](#), such contaminants on the rooftops can pollute RHRW and cause sediment to build up in the rainwater storage tank.

The results showed a continuous reduction in the amount of TSS and turbidity over the six successive flushes ([Figure 2](#)), where each flush represents 0.5 mm diversion to accumulate to 3 mm in total. [Table 2](#) shows a percentage reduction in these measures for the five rainfall events. The analysis of these results showed over 77% reduction in TSS and turbidity after the 3 mm rainwater was diverted. For TSS, the majority of the reduction (i.e. 45% of the 77%) was observed within the first 1 mm diversion, while the least reduction was observed in the third 1 mm diversion (i.e. about 10%). Despite the improvement in turbidity in RHRW following first-flush practices, the result showed that the majority of the turbidity values (after the 3 mm diversion) were still greater than the WHO guideline limits of 5 NTU (shown as the red line in [Figure 2](#)).

**4.1.1.2. Microbial parameters.** The reduction of the microbes in each successive diverted 0.5 mm of rainwater was observed. The results showed that the total coliform and *E. coli* of the harvested FFRW were less than observed in RHRW ([Figure 3](#)). As explored before, the higher values were a result from the deposition of dust/particulate matter and animal faeces on the roof, especially after a long period of dry antecedent days.

[Figure 3](#) evidences a continuous decrease in total coliform and *E. coli* across each successive flush and this finding is consistent for all five rainfall events. [Table 2](#) shows the percentage reduction in the total coliform values for all five rainfall events. The analysis of the result showed that over 78% reduction from the initial microbial values after the 3 mm rainwater was diverted. The majority of the reduction was observed within the first millimetre diversion, while the least reduction of the microbes was observed in the third millimetre diversion. This finding has demonstrated the impact of first-flush practice to control the microbial levels in RHRW.

Although the first-flush practice can potentially produce low-contaminated RHRW, the results from this study have shown that the quality of rainwater is still potentially unsuitable for drinking as benchmarked by the WHO guideline (0 MPN/100 mL). There are some risks associated with drinking RHRW except when it is disinfected. Although several studies have recommended diverting between 0.3 and 2 mm ([Yaziz et al. 1989](#); [Ntale & Moses 2003](#); [Martinson & Thomas 2005](#)), the conclusions from this study based on the pilot results obtained from Ikorodu has initially shown that higher diversion may be required.

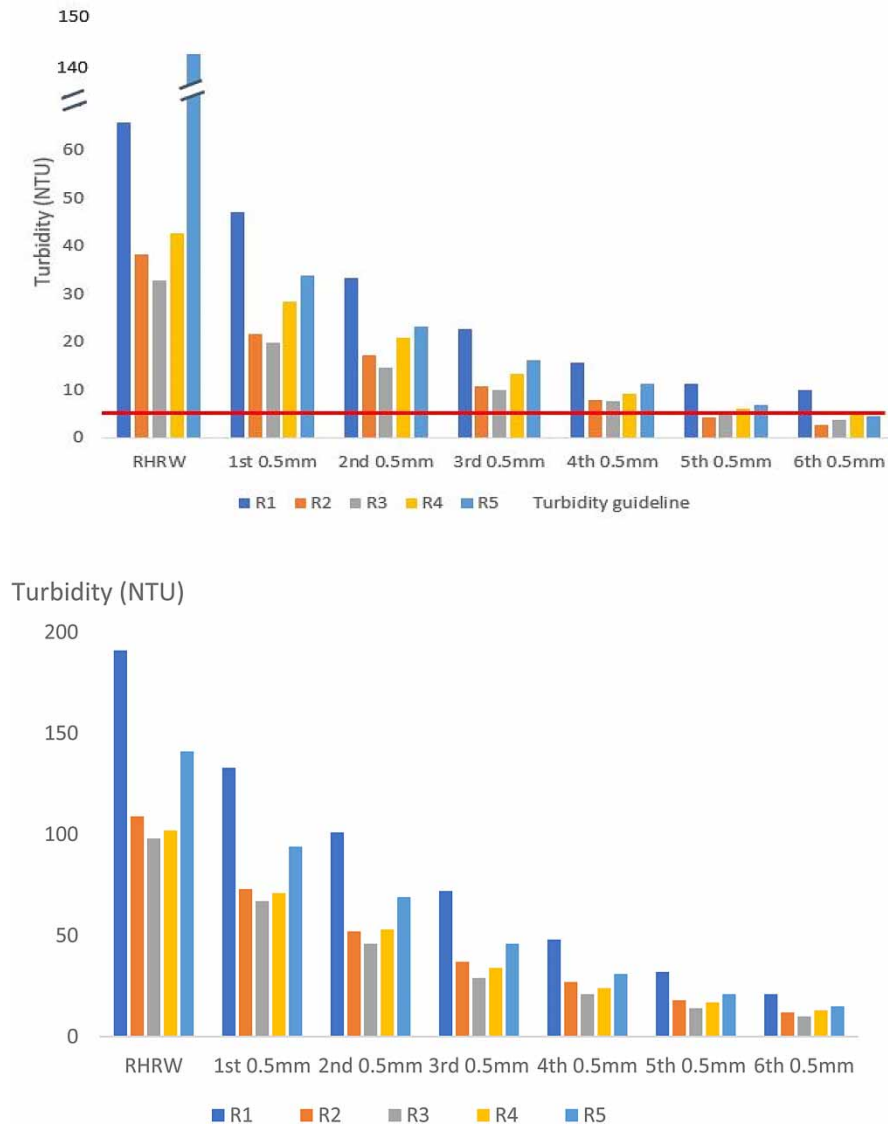
#### 4.1.2. Impact of first-flush on the four constructed roofs

**4.1.2.1. Physical parameter.** The results from the experiments during five rainfall events show that TSS and turbidity from the RHRW are higher than those from the FFRW ([Figures 4 and 5](#)). One of the reasons for higher turbidity and TSS values may be attributed to the accumulation of dust and faecal depositions on the roof as explained in the previous section.

**Table 1** | Rain event characteristics

Rain event number	Total storm depth (mm)	Dry antecedent period (days)
R1	23.7	12
R2	15.4	5
R3	8.9	3
R4	11.6	6
R5	6.2	4

Note: R1, R2, R3, R4 and R5 denote the first, second, third, fourth and fifth rain events, respectively.



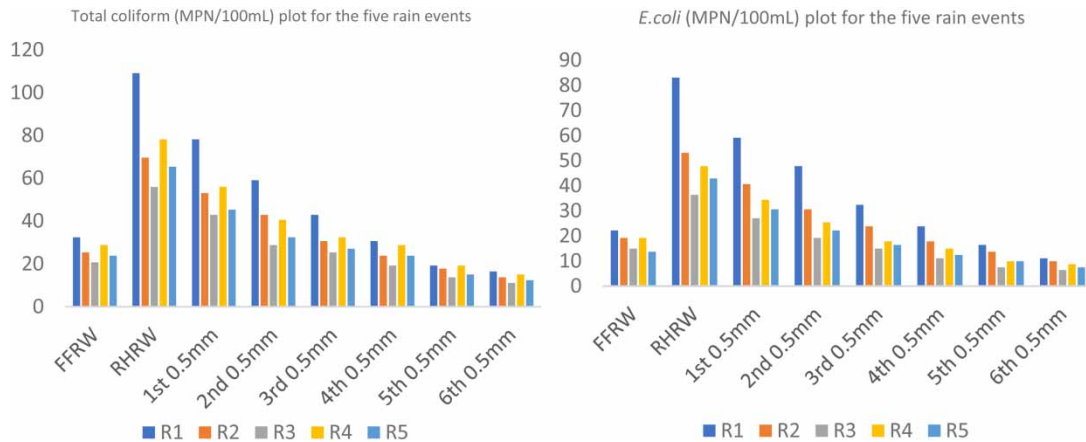
**Figure 2** | TSS and turbidity values (NTU) for the five rain events in an increment of free fall (FF) of 0.5 mm (the horizontal red line denotes 5 NTU). Please refer to the online version of this paper to see this figure in colour: [doi:10.2166/washdev.2021.062](https://doi.org/10.2166/washdev.2021.062).

The results also presented a continuous reduction in TSS and turbidity values over the six successive diversions for all five rainfall events. It was also observed that the majority of TSS and turbidity reduction occurred within the first millimetre diversion of the rainwater. Further analysis revealed an approximate average of 40% reduction between each millimetre diversion of the rainwater. This outcome coincides with the study conducted by [Martinson & Thomas \(2005\)](#), which concluded the reduction to be 50%.

**4.1.2.2. Microbiological parameter.** Consistent with the residential building's roof, microbiological parameters here were analysed for six successive diversions of 0.5 mm rainwater. The analysis of the enumerated microbes over the six successive diversions for the five rainfall events is presented in [Figures 6 and 7](#). Similar to the findings from old building's roof, the figures indicate that the bacterial level from the FFRW is lower than that from the RHRW. Furthermore, the analysis of the results showed a continuous reduction in the bacterial level over the six successive diversions for the five rainfall events. Results also showed that the majority of the bacterial reduction occurred within the first millimetre diversion of the rainwater, with at least over 10% reduction between each millimetre diversion of rainwater.

**Table 2** | Percentage difference of the measured parameters for the five rain events

Measured parameters	Rain events	1 mm	2 mm	3 mm	Total reduction
TSS	R1	47.1	27.7	10.5	85.3
	R2	45.9	21.1	11	78
	R3	53.1	25.5	11.2	89.8
	R4	48	18.6	10.8	77.4
	R5	51.1	27	9.2	87.3
Turbidity	R1	49.5	26.7	8.8	85
	R2	55.2	24.1	12.6	91.9
	R3	52	25.1	10.4	87.5
	R4	50.8	27.8	9.4	88
	R5	48.1	24.5	10.6	83.2
Total coliform	R1	45.8	26.1	13	84.9
	R2	38.4	27.4	14.5	80.3
	R3	48.6	17.1	12.1	77.8
	R4	48.1	15.1	17.6	80.8
	R5	47.4	16.2	15.4	79
<i>E. coli</i>	R1	42.5	28.9	12.2	83.6
	R2	42.4	24.1	12.6	79.1
	R3	47.3	22.3	12.9	82.5
	R4	46.9	21.8	13.2	81.9
	R5	48.3	22.8	11.4	82.5



**Figure 3** | Plots of microbes (MPN/100 mL) for the five rain events.

The analysis of the microbial parameters from different roof materials within this investigation showed that the asbestos roofing gave the worst quality of harvested rainwater (Figures 6 and 7) compared to the other three roofs (plastic, aluminium and galvanised corrugated sheets). The relatively higher quality of harvested rainwater from the other three roofs was a result of their ability to absorb ultraviolet light and hence cause high temperature that can facilitate disinfection of the harvested rainwater. The results from the corrugated galvanised material gave the best microbial quality of harvested rainwater among the four roofing materials. This is due to its ability to absorb more heat in comparison to the others (as also suggested in Martinson & Thomas 2005; Doyle 2006). In addition, the quality of RHRW collected from the new asbestos roof is better than RHRW collected from the 15-year-old asbestos roof. Their difference in the results showed a minimum of 15.9% reduction in the analysed physical and microbial parameters during the same rainfall event (Table 3). This indicates the wear-off from the older asbestos roof behaved as one of the sources of contamination to RHRW.



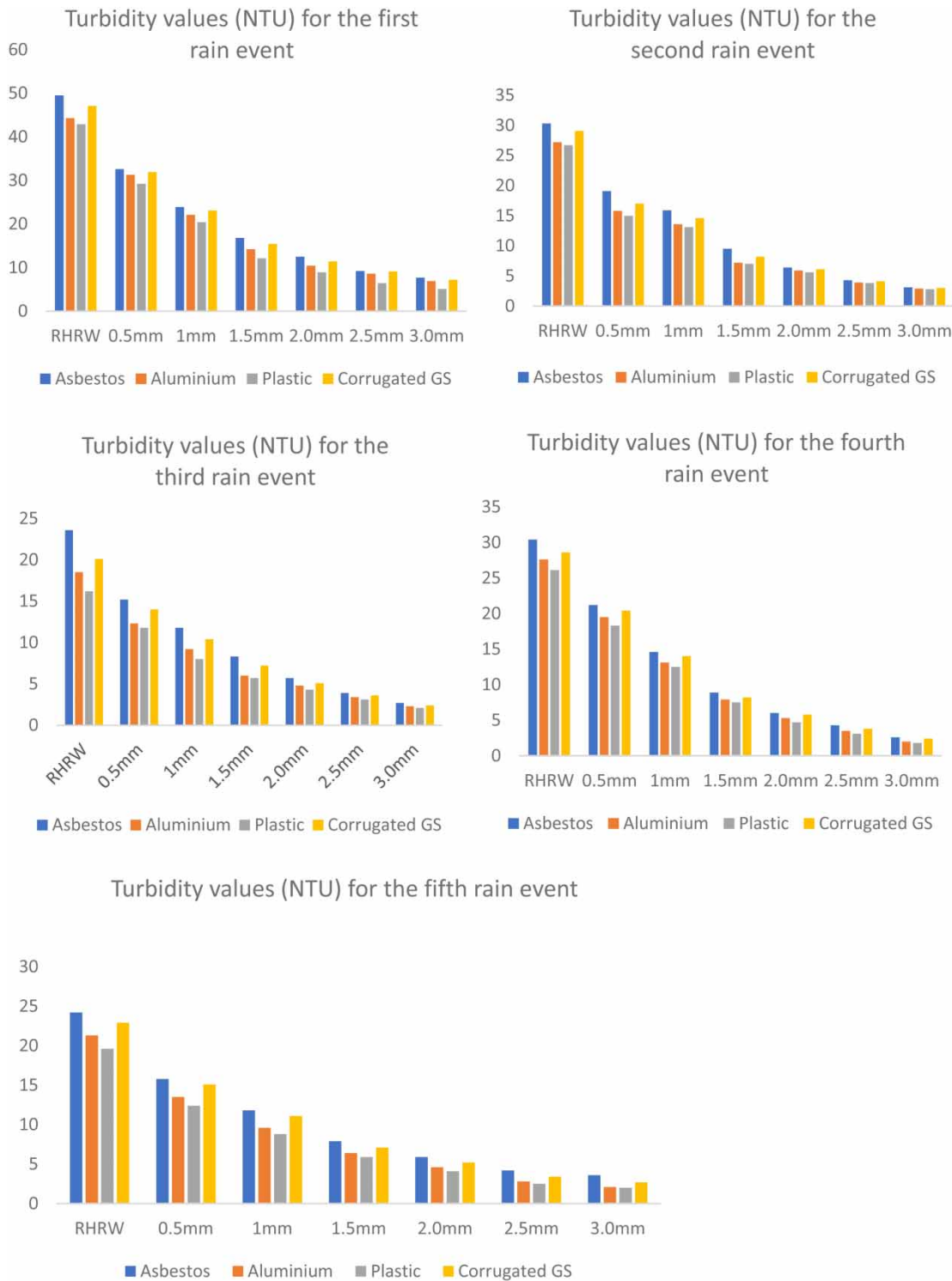


Figure 4 | Turbidity plot (NTU) for the five rain events, respectively.

The investigation further demonstrated a minimum of 75% reduction in the physical and microbial parameters (including TSS, turbidity, total coliform and *E. coli*) over the total of 3 mm diversion for every rainfall event. In the study conducted by [Martinson & Thomas \(2005\)](#) to quantify the phenomenon of first-flush on water quality, it was concluded

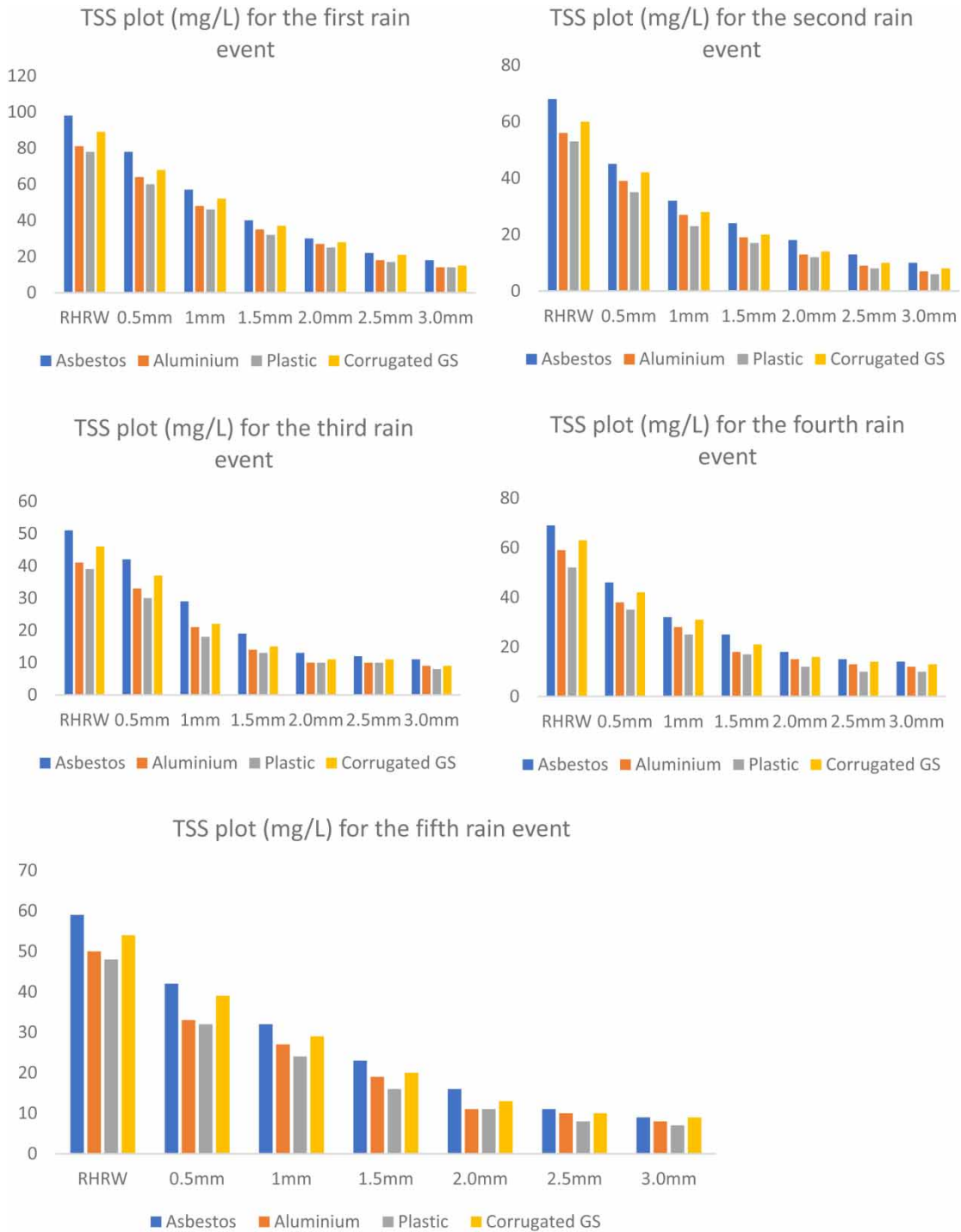


Figure 5 | TSS plot for the five rain events, respectively.

that 85% of the contaminate load can be removed if first-flush has been executed properly. Hence, it can be summarised that this study’s first-flush experiments on RHRW have been executed reasonably well to achieve its planned outcome; however, the practice of first-flush will not completely rid the water impurities. Therefore, it is recommended that HHTTs are used especially if the harvested water is intended for human consumption. The results from the experiments also

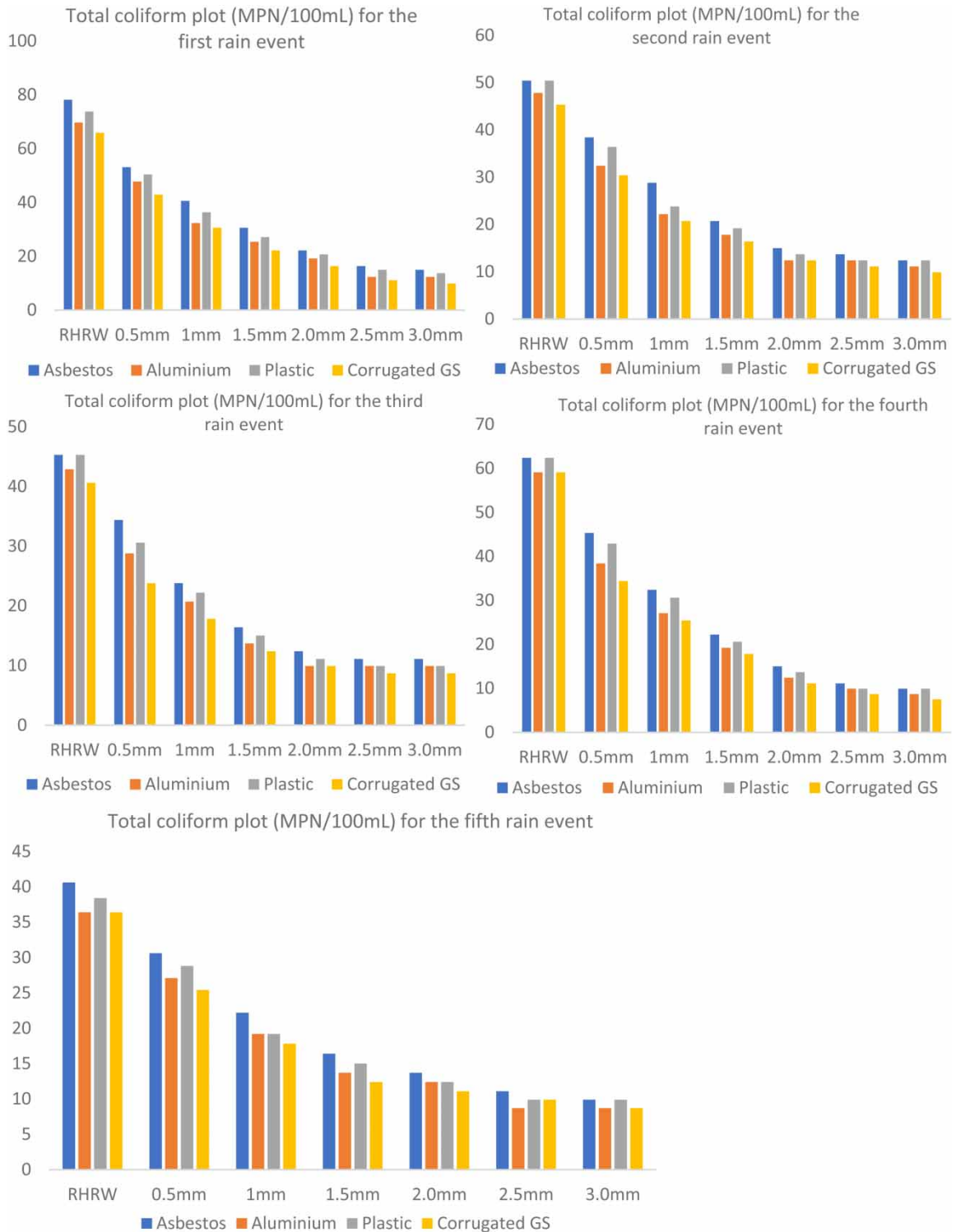


Figure 6 | Total coliform plot for the five rain events, respectively.

showed that the quality of the harvested rainwater after a longer period of dry antecedent days was poor due to the depositing of more contaminants on the roof. This conclusion has been drawn collectively from the analysis presented in Figures 2-7 and Tables 2 and 3.

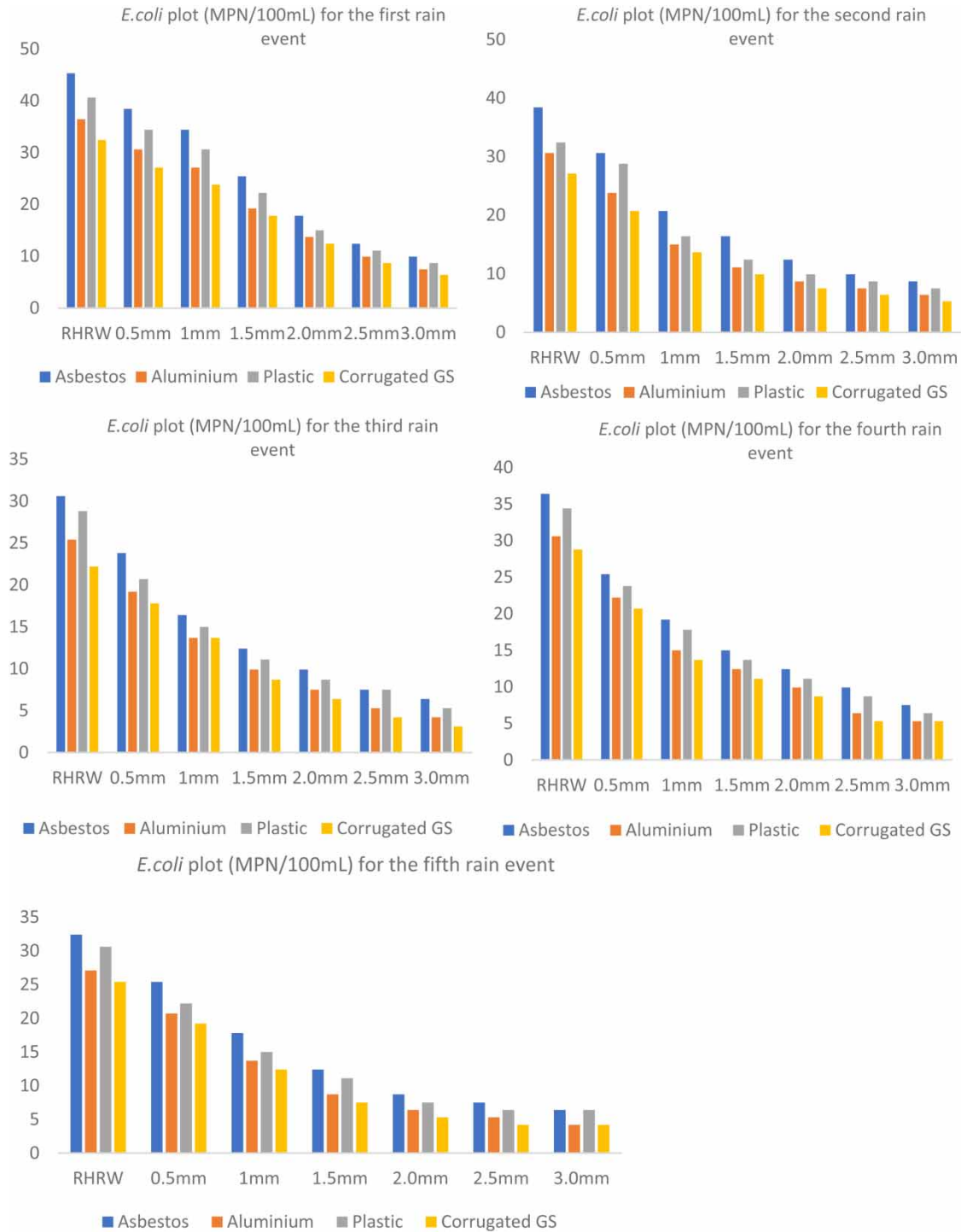


Figure 7 | *E. coli* plot (MPN/100 mL) for the five rain events, respectively.

## 4.2. HHTTs

### 4.2.1. Results and discussion

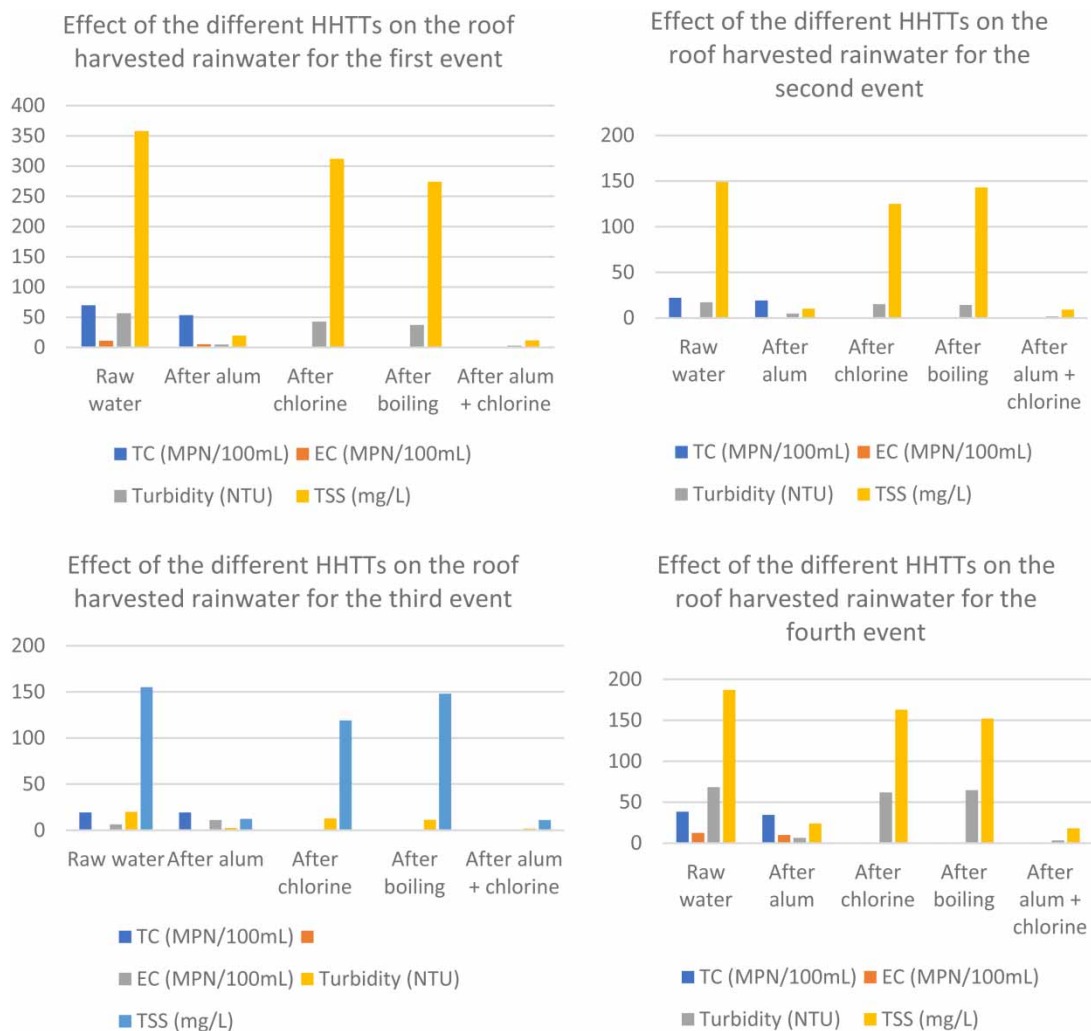
As outlined previously, the HHTTs used in this study include alum, boiling, chlorine and a combination of alum and chlorine. The results from the application of different HHTTs show that the combination of alum and chlorine, and alum alone have a significant effect on turbidity and TSS, while boiling and chlorination have much less effect on these physical parameters

**Table 3** | Percentage difference obtained on the results from both asbestos roof

Rain events	TSS (mg/L)			Turbidity (NTU)			Total coliform (MPN/100 mL)			E. coli (MPN/100 mL)		
	Old asbestos	New asbestos	%Diff.	Old asbestos	New asbestos	%Diff.	Old asbestos	New asbestos	%Diff.	Old asbestos	New asbestos	%Diff.
R1	191	98	48.69	65.8	49.5	24.77	109.1	78.2	28.32	83.1	45.3	45.49
R2	109	68	37.61	38.2	30.3	20.68	69.7	50.4	27.69	53.1	38.4	27.68
R3	98	51	47.96	32.7	23.6	27.83	56	45.3	19.11	36.4	30.6	15.93
R4	102	69	32.35	42.5	30.4	28.47	78.2	62.4	20.20	47.8	36.4	23.85
R5	141	59	58.16	148.9	24.2	83.75	65.4	40.6	37.92	42.9	32.4	24.48

Notes: R1, R2, R3, R4 and R5 denote the first, second, third, fourth and fifth rain events, respectively. %Diff. denotes the percentage difference.

(refer to Figure 8). Alum can cause the particles to clump together, thus ensuring easy settling. The application of alum together with filtration improves the clarity of water. Microbes (viruses, bacteria and protozoa) are characteristically attached to solids; therefore, the sediment filtration causes the reduction of turbidity and can effectively decrease microbiological pollution in water. The elevated levels of turbidity also shield the microbes from the chlorination effect and encourage the growth of bacteria, which can lead to a significant rise of chlorine use in order to increase its effectiveness.



**Figure 8** | Effect of the different HHTTs on the harvested rainwater for the four rain events, respectively.



It was observed that the use of boiling, chlorine and combination of alum and chlorine can effectively remove the total coliform and *E. coli*, while the very little reduction was observed by the addition of alum alone (Figure 8). The insignificant reduction of bacteria by alum was caused by the fact that alum is a coagulant rather than a disinfectant. Furthermore, the study conducted by Spinks *et al.* (2006) recommends that: (1) the temperature range between 55 and 65 °C is decisive for effective elimination of pathogenic bacteria and (2) drinking hot water systems should operate at a minimum temperature of 60 °C. The results from our study support these recommendations.

#### 4.2.2. Test and result limitations

Five different rainfall events were harvested for the first-flush tests and these were conducted on five different roofs (i.e. one residential roof and four constructed roofs), while the other four different rainfall events were harvested and used to analyse the HHTT experiments. Even though the analysis of the results from the rainfall events showed a consistent pattern to the literature (Figures 2–8), more tests can be conducted in the future to further investigate and strengthen the proposed analysis. In particular, the effect of first-flush for wider roof types and more diverse communities can be inspected. Besides, a wider range of HHTTs should also be tested with more rounds of repetitive experiments to ensure their findings.

In terms of utilised roofs for this study, the newly built roofs have been compared to one existing roof. It is recognised that the existing roof was 15 years old and has been through weather changes each year. This increases its resistance to run off and probably retaining pollutants longer during the rainfall event, which can impact its general state and the quality of runoff collected. For future studies, i.e. when more time and resources can be allocated, other common existing roofs within the area can be investigated to identify any potential result discrepancy with this study.

## 5. CONCLUSION

In this study, the field experiments were conducted in the Ikorodu area of Lagos state, Nigeria, to investigate the impact of first-flush and HHTTs, i.e. chlorine, boiling, alum and combination of alum and chlorine, on the quality of RHRW. The application of HHTTs to RHRW evidenced that boiling and chlorination can effectively decrease the bacteria level (i.e. reduce total coliform and *E. coli*), while alum had more impact in reducing the turbidity and TSS. It has been further illustrated that a combination of chlorine and alum can provide the synergy effect required to significantly reduce turbidity and bacteria.

A minimum reduction of about 40% from the original contaminant load was observed in every first-flush experiment. Furthermore, our study found that RHRW with the best microbial quality was collected from the corrugated galvanised roofing material compared to other materials. Although the results have suggested that the practice of first-flush can improve the RHRW quality, it is suggested that the HHTTs are co-employed especially if the harvested rainwater is to be consumed.

## ACKNOWLEDGEMENTS

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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