ANALYSIS OF FIRST FLUSH OF ROOF RUNOFF AND WASH OFF PROCESS OF THE DIFFERENT ROOFING MATERIALS

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ABSTRACT

The effects of the first flush together with a particular roofing material are often considered negligible. Research on this area of study is limited and leaves a greater area yet to be explored. The aim of this study was to understand the wash-off response of different roofing materials in the context of first flush and hence to contribute the knowledge for the design of effective rainwater harvesting systems targeting the portable usage. The study was conducted by collecting the first flush from three roofing materials namely Clay tiles, Asbestos sheets and Corrugated Steel for a period of three months. Seasonal variations were not considered. The samples were collected, stored and analyzed for key physio-chemical water quality parameters namely, pH, Colour, Hardness, Sulfate, Turbidity, Total Suspended Solids, Cadmium, Aluminium, Lead, Nickel according to standard procedures. It is clear that the quality of the first flush of roof wash-off strongly depends on the type of roofing material. Wash-off of Tile Roof is the least polluted whereas the Asbestos roof is the most polluted. However, the direct use of harvested rainwater for portable purposes should be further investigated based on the micro biological quality variation. In addition, results revealed that the use of Turbidity, pH and EC can be used as surrogate indicators to evaluate the roof surface water quality.

***Key words*:** First Flush, Wash-off Process, Different Roofing Materials

1. INTRODUCTION

The entire world is facing a major shortage of usable water [1]. Even though 2/3rd of the entire planet is covered with water the availability of fresh water is limited [2, 3].

On the other hand, several research studies have shown that increase of percentage of impervious surfaces with rapid urbanization dramatically impacts on both quantity and quality of the fresh water resources [4]. Moreover, urbanization together with the increase in urban population considerably increases the amount of daily water consumption [5]. Consequently, high pressure on water supply has already been placed on rapidly growing towns and cities in everywhere.

In lieu of this situation various methods are employed with the sole purpose of increasing the amount of usable water. Rainwater harvesting is one such method which already has drawn a considerable attention as an additional source of water to supply demand in many parts of the world.

Notably Sri Lanka too is undergoing rapid urbanization with the increase population together with the increase life expectations such as education and employment. Though it has not yet been identified as a major threat right now, it is highly possible that there be a shortage of water of rapidly developing towns such as Malabe in coming decades due to its rapidly developing industrial and social environment. Consequently, it is of vital importance to investigate possible methods to increase the availability of usable water in the area.

In this context, rainwater harvesting can be considered as a viable option for an area like Malabe due to the abundance of rain in the area. Although this is not a new concept to the many parts of the country, the familiarity upon the subject as a portable source of water supply such as for drinking and cooking remains below average.

Hence, the primary objective of this project was to understand the wash-off response of different roofing materials in the context of first flush of roof runoff. The knowledge generated aims to contribute for the design of effective rainwater harvesting systems targeting the portable usage.

2. METHODOLOGY

2.1. Study area

Malabe is situated within 10 km from Colombo which is the capital of Sri Lanka. As an area currently undergoing a rapid development, Malabe shows great prospects of rising to be a future smart city in the country.

General climatic conditions of Malabe include temperature varying from 27^{o}C to 33^{o}C during daytime and 22^{o}C to 25^{o}C during the night and also an average annual rainfall of about 2120 mm.

Malabe contains a population of 231,080 (close to 1/10th of the entire population of the Colombo district) people within a 7 km radius from its center. This city also houses several leading education institutes covering the fields of engineering, medicine, IT, management, etc. It is also the epicenter for industrial areas such as Biyagama and Hokandara.

Within the last decade alone, Malabe city has given rise to more than 5 large scale housing schemes and a great improvement in its infrastructure facilities which primarily include road network, hospitals, IT companies, banks and schools.

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Figure 1: City of Malabe

2.2. Data collection

This research was conducted in three main steps based on the requirement of collecting and analyzing of data. The steps were as follows;

1. Identification of the most commonly used roofing materials
2. Design, construction and setting up of the model roofs in an environment with controlled parameters.
3. Sample Collection and testing of the key physio-chemical water quality parameters.

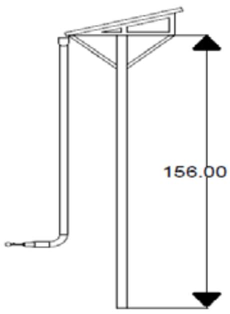
2.2.1. Identification of the most commonly used roofing materials

A pilot survey was conducted to identify the most commonly used roofing materials in Malabe city and its sub urban areas. For this purpose, roofs of both residential and commercial buildings were randomly selected. In order to investigate the frequency of roof type distribution, most commonly used roof types were selected. These types were namely Clay tiles, Asbestos sheets, Corrugated steel sheets, Fiber sheets and concrete tiles.

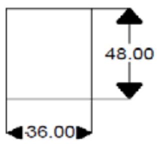
Based on the results of the pilot survey, it was decided that the controlled experiments to be conducted using three types of roofing materials namely Clay tiles, Asbestos sheets and Corrugated steel sheets.

2.2.2. Design, construction and setting up of the model roofs in an environment with controlled parameters

With the intentions of simulating the conditions required for the collecting of the first flush of rainwater, three model roofs, 1 each from the each of selected roofing material were designed and constructed. These roofs were designed, constructed and placed satisfying the general requirements of a standard roof. The schematics of the model roofs are shown in Figure 2.



(a) Side view



(b) Top view

Figure 2: Schematics of the model roof (dimensions are in inches)

Also, the first flush collection mechanism was designed as shown in Figure 3. As can be seen in Figure 3 from Right to Left, it consists of a 90^0 bend fixed in to 3” diameter pipe, which is reduced progressively from 3” to 2” and 2” to 0.5” respectively and ending in a ball valve.

Figure 3: Schematics of the first flush device

Figure 4 shows the deployment of the model roofs in the field.

(a) Front view

(b) Rear view

Figure 4: Final construction and arrangement of model roof in the field

2.2.3. Sample collection, testing and data analysis

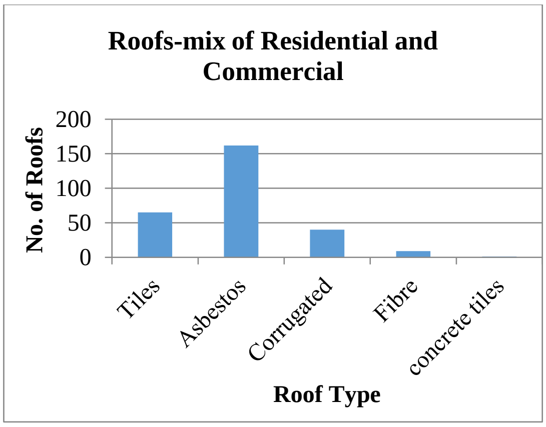
Seven samples from each roof surface were collected during seven different rain events. All the samples were collected, stored and tested according to the standard methods of water and waste water testing [6]. The samples were tested for a set of key water quality indicators namely pH, Color, Hardness, Sulfate, Turbidity, Total Suspended Solids (TSS), Cadmium (Cd), Aluminium (Al), Lead (Pb) and Nickel (Ni).

Data analysis was conducted basically in two stages. Firstly, the analysis was conducted by obtaining an average for each parameter under each roof type and comparing the variation between each type.

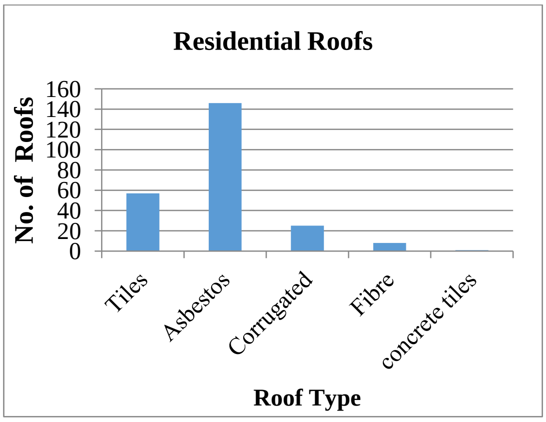
Secondly, raw data was subjected to Principle Component Analysis (PCA) in order to identify the nature of the wash-off process on different roofing materials and correlation between variables. PCA is a well know multivariate data analysis technique employed for pattern recognition and to visually display the relationships between variables and objects [7]. The PCA was conducted with the support of XLStat 2014.

3. RESULTS

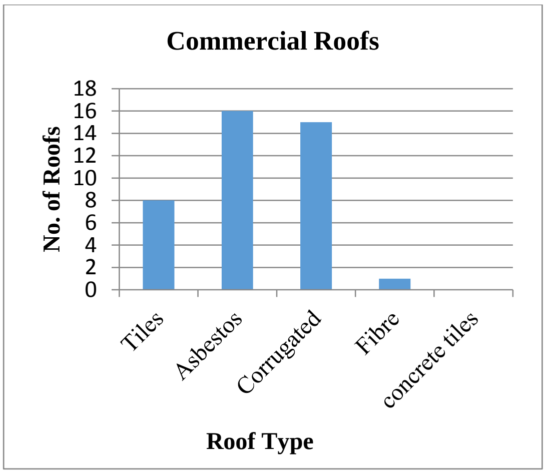
Figure 5 shows the results of the pilot roof survey.



(a)



(b)

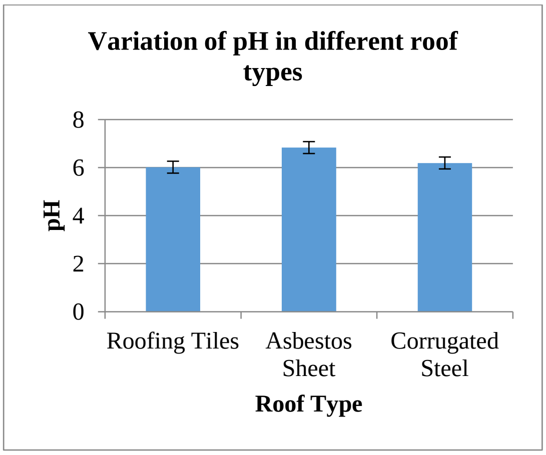


(c)

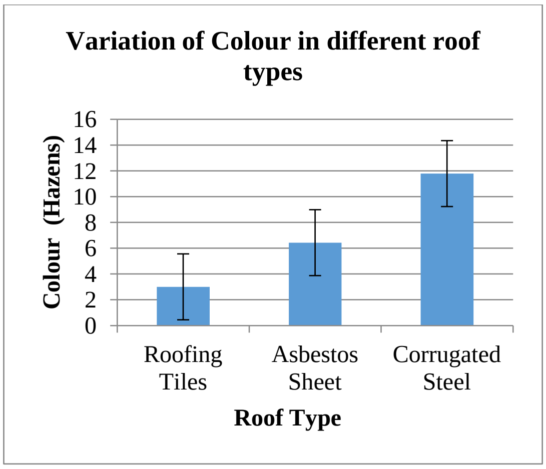
Figure 5: Distribution of the roofing material used

It can be clearly seen that Clay tiles, Asbestos sheets, and Corrugated steel sheets are widely used in and around Malabe, where in most cases, the use of Asbestos is considerably high when compared to the other two types except when considering roofs of commercial buildings, where corrugated steel sheets too show almost equal importance. Consequently, three model roofs were designed and constructed using clay tiles, asbestos sheets and corrugated sheets

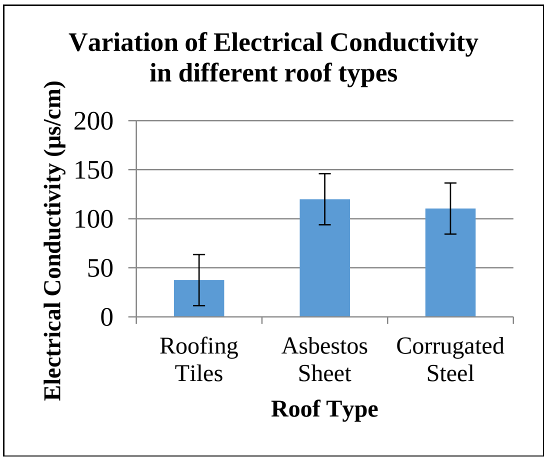
Figure 6: depicts the variation of different water quality parameters tested between three roofing materials.



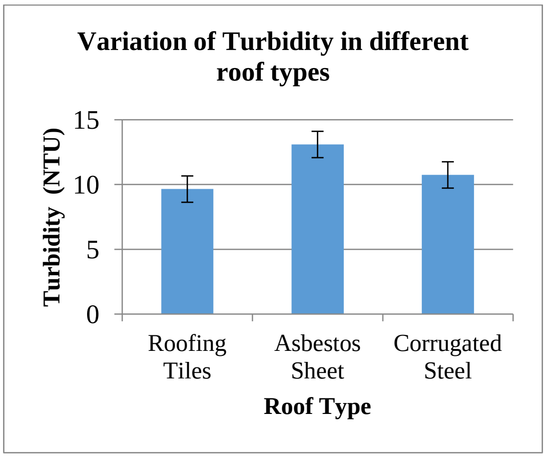
(a) pH



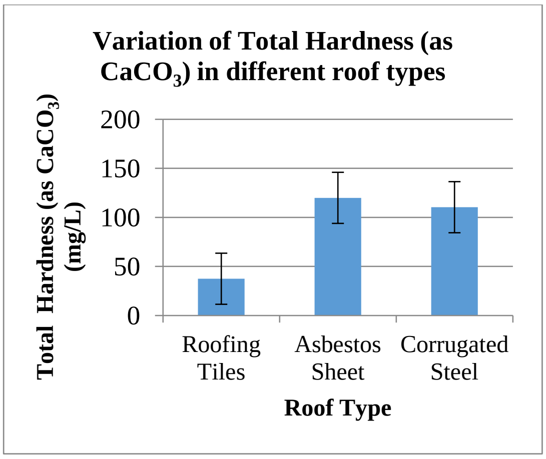
(b) Colour



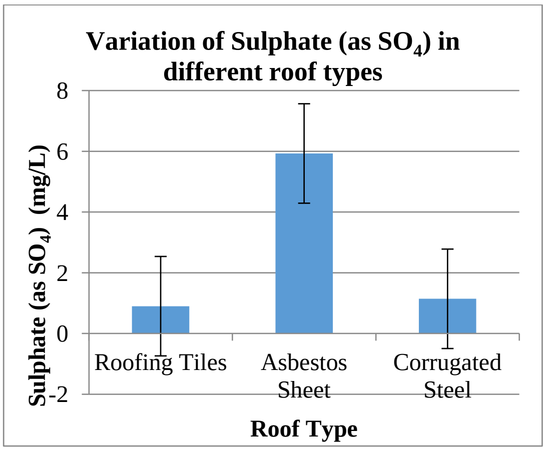
(c) Electrical Conductivity



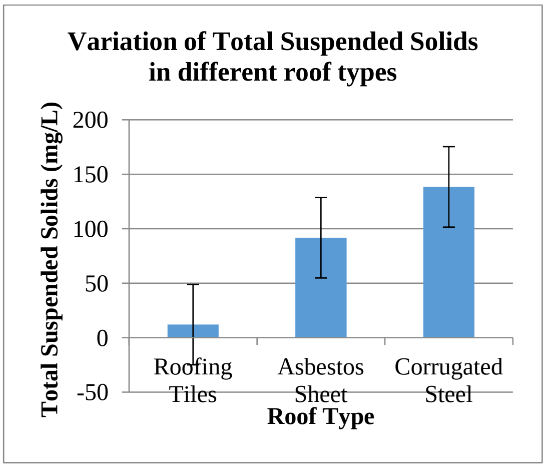
(d) Turbidity



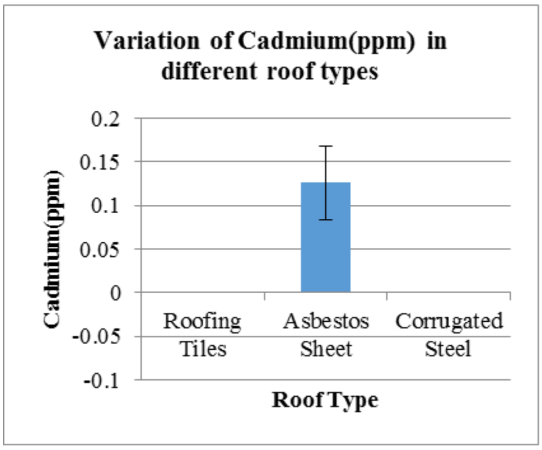
(e) Total Hardness



(f) Sulphate



(g) Total Suspended Solids



(h) Cadmium

Figure 6: Variation of different parameters with reapect to the roof type

As discussed in Section 2.2.3 this analysis was conducted considering the average values of each parameter obtained for the set of samples collected for each roof surface.

It should be noted that Aluminium, Lead and Nickel have not been detected in any of the wash-off samples although they are found as components of the three roofing materials. However, as the sample collection in this research was conduted only for a short duration like three months the long term wash-off phenomenan still worth to be investigated due to the decaying of material which can occur with prolonged climatic conditions.

As depicted, it can be seen that out of the eight parameters tested, the asbestos roof has shown the highest readings in six parameters followed by Corrugated steel in the other two parameters whereas Tile roofs show considerably lower values for most of the parameters. This indicates that the least polluted nature of Tile Roofs compared to other two types. This can be attributed to the difference of the surfce texture and hence the pollutant wash-off characteristices of these materials.

The levels of pH, EC, Turbidity, Hardness, Sulphate and Cadmium are higher in the Asbestos roof than in the other roofs.

However, the level of pH for all three roofing materials does not show a considerable variation when compared with the other parameters and remains within the safe range of pH for drinking water which is between 6.5 – 9.5 [8].

Furthermore, the levels of EC, Sulphate and Hardness are also within the safe limits in all three roofs. Notably, the level of Cadmium is 25 times higher in Asbestos Roof than the acceptable Cadmium concentration for drinking water whereas it is almost undetected in the other two roof types [8]. The level of Turbidity is higher than expected in Asbestos and Corrugated steel roofs but the level is just below what is expected in tile roofs [8]

Moreover, the levels of Colour and Total Suspended Solids (TSS) are considerably higher compared to the acceptable limits for drinking water in the Corrugated steel roof which is followed by the Asbestos roof [8]. On the other hand the amount of TSS in wash-off of Tile roof is significantly low (about 4 times lower than the safe limit [8]) compared to the other two roofing materials. This can again be attributed to the surface texture of Tile roof where pollutant can strongly adhered to the surface due to its coarse surface texture.

So far it is clear that, wash-off of Asbestos roof is the most polluted where as Tile roof is the least . Also, it is evident that the amount of solids washed off by Corrugated steel roofs is very high.

Figure 7 shows the PCA biplot obtained from all the raw data collected from each roof.

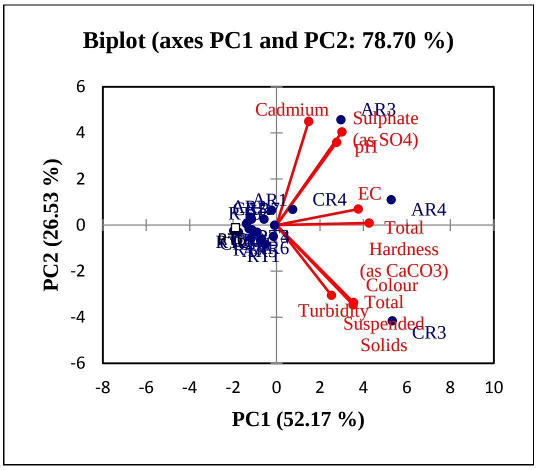


Figure 7:Biplot from the Principle Compoment Analysis (PCA) of all the data collected from all three roofs. (RT-Tile Roof, AR-Asbestos Roof, CR-Corrugated Steel Roof, EC- Electrical Conductivity)

It can be seen that except for four of the data points all of the other data points are grouped as one cluster. This indicates that the similarity between the wash-off process of three roofing materials. It can be sugessted that eventhough the wash-off process remains same in all the roofing materials the amount of the pollutant wash-off depends on the amount of pollutant build-up and the surface texture. Also Figure 7 shows, strong correlation between Turbidity and TSS, pH and Sulphate, and EC and Total Hardness. This suggests that the possibility of using Turbidity, pH and EC as surrogate indicators to evaluate the roof surface water quality due to the less cost and time associated with the measurement of these parameters. The PCA further shows a negative correlation between Cd and TSS. This impiles that the wash-off of Cd is in the dissolved phase which is more difficult to eliminate.

4. CONCLUSION

It is clear that the quality of the first flush of roof wash-off strongly depends on the type of roofing material. However, the pollutant wash-off process does not depend on the type of roofing material whereas the amount wash-off depends on the amount of pollutant build-up and the surface texture. Out of the three commonly used roofing materials compared in this study it can be concluded that the wash-off of Asbestos roofs is the most polluted whereas Tile roof is the least polluted. Consequently, Tile roofs can be recommended more compared to the Asbestos and Corrugated roofing as a source of rainwater harvesting for non-portable purposes. However, the direct use of harvested rainwater for portable purposes should be further investigated based on the micro biological quality variation as that was not investigated in this study. The results also indicate importance focusing on dissolved fraction of wash-off in the context of Cd. In addition, the use of Turbidity, pH and EC as surrogate indicators to evaluate the roof surface water quality can be recommended.

5. ACKNOWLEDGEMENTS

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