EVALUATION OF THE QUALITY OF HARVESTED RAINWATER FROM DIFFERENT ROOFTOPS: A CASE STUDY FROM SOUTHWEST COASTAL REGION OF BANGLADESH

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ABSTRACT

Harvested rainwater has been used widely as an alternative drinking water option in many areas of the southwest coastal region of Bangladesh due to salinity intrusion and arsenic contamination in the drinking water sources. This study evaluated the impacts of roofing materials (asbestos, concrete, and iron sheets) on the physicochemical and microbial contamination of harvested rainwater. The samples were collected from Paikgacha Upazila, Khulna, Bangladesh covering the mentioned possible rooftop types during monsoon (July 2022) and brought to the Laboratory of Environmental Science Discipline of Khulna University for microbial, heavy metal, and microplastic analysis using membrane filter technique, Flame Atomic Absorption Spectrometer (FAAS), and microscopic observation respectively. Rainwater collected from iron sheets had reduced levels of fecal coliform (130 CFU/ 100 mL), and pathogenic bacteria Salmonella sp. and Vibrio cholerae compared with rainwater collected from other roofing materials. Besides, among different roofing materials, iron sheets exhibited the greatest lead content (12.67 ± 0.61 µg/L), followed by concrete and asbestos roofs respectively. Elevated nickel (12.67 ± 0.61 µg/L) and chromium (17.39 ± 1.59 µg/L) levels were also observed in rainwater collected from iron sheets, whereas concrete and asbestos roofs displayed lower concentrations of these elements. Furthermore, concrete roof-oriented rainwater samples had the highest microplastic content (34 MPs/L) while iron sheets contained the lowest (24 MPs/L). Further investigations are needed on a large number of samples to identify contaminants and develop effective, economically viable rainwater harvesting systems with treatment options.

Keywords: *Rainwater, pathogenic microorganisms, heavy metal, microplastic, contamination*

1. INTRODUCTION

The southwest coastal region of Bangladesh faces a significant shortage of freshwater supplies due to substantial amounts of salt and arsenic pollution in groundwater (Abedin & Shaw, 2012). As a result, the people in this area must depend on rain-fed ponds and rainwater harvesting systems (RWHS) for their water supply (Islam *et al*., 2011). RWHS is one of the sustainable freshwater sources in the coastal areas of Bangladesh, and several initiatives and projects have recently been started to promote and build rainwater collection systems in both coastal and arsenic-affected regions (Karim *et al*., 2005). The coastal regions in Bangladesh have traditionally used small-scale rainwater harvesting to meet their drinking water needs. In places with major salinity problems, over 36% of households use rainwater harvesting for drinking purposes during the rainy season, and one of the most prevalent ways to do this is by collecting rainwater through the roof (Hussain and Ziauddin, 1992).

In the southwest coastal area of Bangladesh, the roof serves as the catchment area for rainwater collection, and a gutter system connects the roof to the storage tank. Rainwater can be collected from any type of roof, but the cleanest water comes from concrete, tiles, and metal roofs (Ahmed, 1999). Rainwater from the roof run-off is collected and stored in appropriate water tanks. It is typically safe for residential use if collected properly, however, difficulties may develop if the roofs become significantly contaminated due to the accumulation of contaminants from the atmosphere as well as animal droppings (Yaziz *et al*., 1989). Lee *et al*. (2012) demonstrated that the type of roofing material utilized has some bearing on the quality of rainwater captured in terms of the physical, chemical and biological characteristics.

The roof and gutter of an RWHS may be exposed to the feces of birds, insects, mammals, and reptiles, which may contain a wide range of pathogens (A. Islam et al., 2019). Animal droppings and other organic debris that have been deposited on the roof and gutter after rain events may therefore be carried into the tank by roof runoff (Ahmed *et al*., 2011). Numerous studies around the world have detected elevated levels of coliform bacteria contamination in rainwater tanks (Spinks *et al*., 2006; Lee *et al*., 2010; de Kwaadsteniet *et al*., 2013).

In addition to microbial contamination, heavy metals are also found to be prevalent in roof-harvested rainwater (Quek & Förster, 1993; Simmons et al. 2001; Islam *et al*., 2010). Exposure to heavy metal-contaminated drinking water has severe effects on human metabolism (Fu & Xi, 2020) as the metals in water are more readily absorbed by the human body than in food, the toxicity of metals ingested through drinking water may be greater than that of metals ingested via food (Islam *et al*., 2019). Exposure to lead, cadmium, mercury, and arsenic poses the greatest risks to human health when it comes to heavy metals (Järup, 2003).

In the southwest coastal region of Bangladesh, PVC pipes and plastic storage tanks are used for rainwater collection (Biswas & Mandal, 2014). So, there is a significant risk of microplastic decay as the water is stored for an extended period. Microplastics (MPs) have been reported as heavy metal and microorganism carriers with a variety of interactive effects (Liu et al., 2021; Qiu et al., 2022).

This work is the pioneering investigation in Bangladesh that integrates analysis of microbiological, heavy metal, and microplastic contamination in harvested rainwater. This research will offer baseline data on the quality of harvested rainwater in terms of microbial, heavy metal, and microplastic contamination, as well as the variation in their abundance across different types of catchments. The findings of this study will be helpful in initiating further studies to address the challenges and ensure that people in this area have access to safe drinking water.

2. METHODOLOGY

2.1 Study Area

All the samples for this study were collected from the Goroikhali Union, Paikgacha, Khulna, having coordinates 22.88° N latitude and 89.55° E longitude. A reconnaissance study was undertaken to establish the best location for roof-harvested rainwater accessibility, as residents in these areas use harvested rainwater for both non-potable and potable purposes.

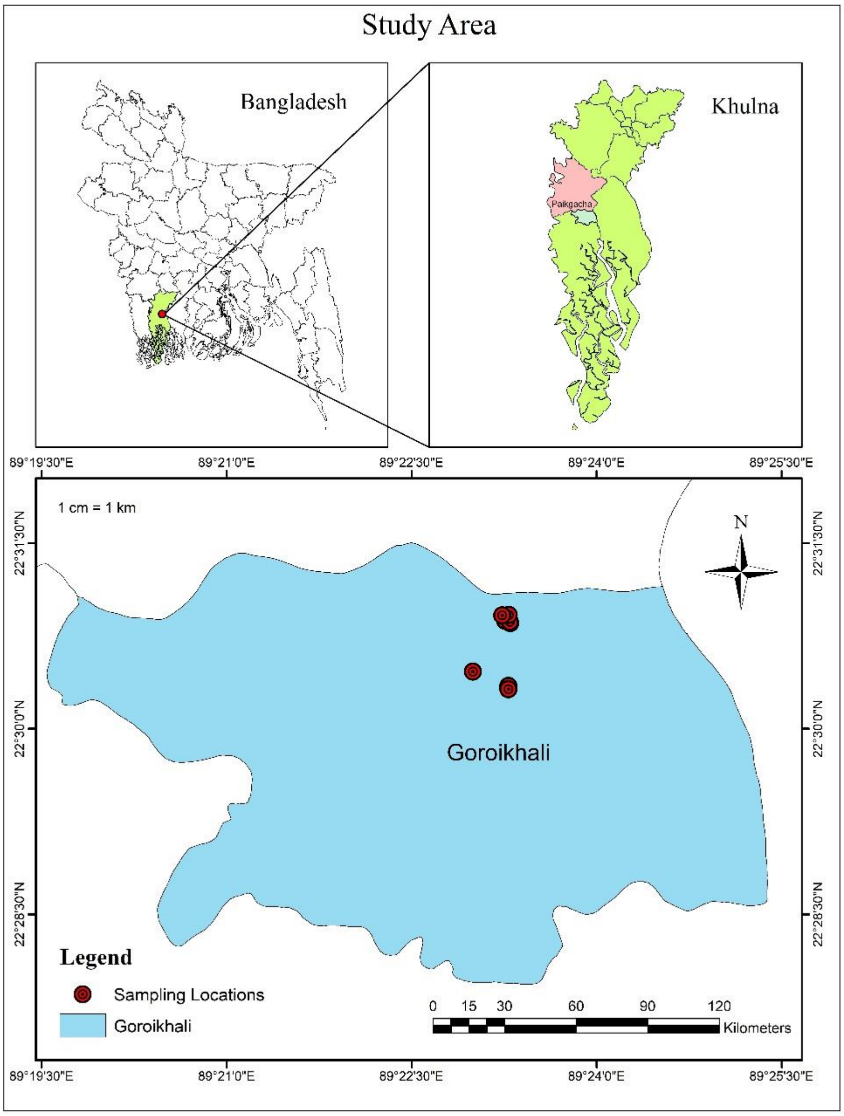

Figure 1: The study area map with sampling location

2.2 Sample Collection and Processing

A total of 27 water samples were collected from households in Goroikhali Union, Paikgacha, using 500-mL plastic and glass bottles during monsoon (July 2022) for microbial, heavy metal and microplastics analysis. As there were three major types of roofs (asbestos, concrete and iron sheet) available for collection of rainwater and stored in a plastic tank, the samples were collected from the plastic tanks. then they were covered with foil paper, and stored separately in an ice box for further analysis.

The plastic bottles were sterilized either autoclaved at 121°C for an hour before being collected for microbiological analysis. Four to five drops of an aqueous sodium thiosulfate solution were used to inactivate residual chlorine before sterilizing the plastic bottles.

The heavy metal analysis involved washing plastic bottles and vials with a phosphate-free detergent, nitric acid, ultra-pure water, and drying them in a lead-free atmosphere. To measure concentration, 65% concentrated HNO_3 acid was added, reducing pH to below 2, preventing precipitation and adsorption onto container walls.

The MPs analysis process involved cleaning bottles with deionized water and detergent, drying them, and filtering out MPs (Liebezeit & Dubaish, 2012). Filters were rinsed with water, they were vacuum-filtered through a cellulose nitrate filter (0.45 m pore size, Sartorius AG, Germany), and fresh filters were added as needed. The samples were dried and stored for later examination on petri dishes with labels, with fresh filters added as needed.

2.3 Experimental Work

2.3.1 Identification of Indicator and Pathogenic Bacteria

Water is commonly tested for three types of coliform bacteria: fecal coliforms (FC), total coliforms (TC), and E. coli. The standards for drinking water are based on TC, FC, and E. coli. The accepted standard for drinking water is that there should be no coliforms present after filtering or treating (APHA, 1998). Water samples were filtered using a 0.45 µm pore-size membrane filter and placed on m-Endo agar plates to identify TC colonies. The plates were incubated at 44°C for 18–24 hours to count TC colonies. For the enumeration of FC and Escherichia coli, 100 ml of water samples were filtered using a 0.45 µm pore-size membrane filter and placed on membrane fecal coliform (mFC) and m-TEC agar plates. The plates were incubated at 35°C for 2 hours and again at 44.5°C for 22-24 hours to count E. coli colonies. Red or magenta colonies were E. coli, while characteristic blue colonies were FC. To test for Salmonella presence, 100 mL of water samples were filtered using a 0.45 µm pore-size membrane filter and placed on agar plates. The plates were incubated at 35°C for 24 hours to count pink colonies (Hara-Kudo *et al.*, 2001).

2.3.2 Heavy Metal Analysis

The presence of lead, cadmium, nickel and chromium in harvested rainwater was determined by the use of Flame Atomic Absorption Spectrometry (FAAS) (APHA, 2000).

2.3.3 Visual Identification and Quantification of Microplastics

Filter membranes were visually inspected using an Amscope digital camera and IM660 TI Biological Microscope (Zarfl, 2019). MPs were categorized into fibers, fragments, film, and pellets based on their recognizable properties. This study aimed to compare the types and concentrations of microplastics in harvested rainwater, providing better knowledge of their sources and a more accurate calculation of the total number of MPs present in the water. The study aimed to provide a better understanding of microplastic sources.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Microbial Contamination in Different Rooftops Harvested Rainwater

The study discovered variations in the quantity of microorganisms on various rooftops, with the most occurring in asbestos-harvested rainwater. Total Coliform outnumbered other bacterial species (897 CFU/100mL) and did not significantly differ among rooftops. The concentrations of fecal coliforms differed across rooftops, with the maximum concentration (652 CFU/100 mL) found in asbestos harvests and the lowest (130 CFU/100 mL) in iron sheet harvests; however, these differences were not statistically significant ($p = 0.196$). Meanwhile, E. coli contamination variation among rooftop types was statistically significant ($p = 0.042$), with asbestos contamination being higher than iron sheets, but no significant differences were found between asbestos and concrete or concrete and iron sheets ($p = 0.1070$). The study found low Salmonella spp. concentration in harvested rainwater, with a small amount found on asbestos and iron sheet roofs, 4 CFU/100mL both, and no Vibrio cholerae species in the samples. However, Bangladesh water quality standards support no microbial presence in drinking water (DPHE, 2019).

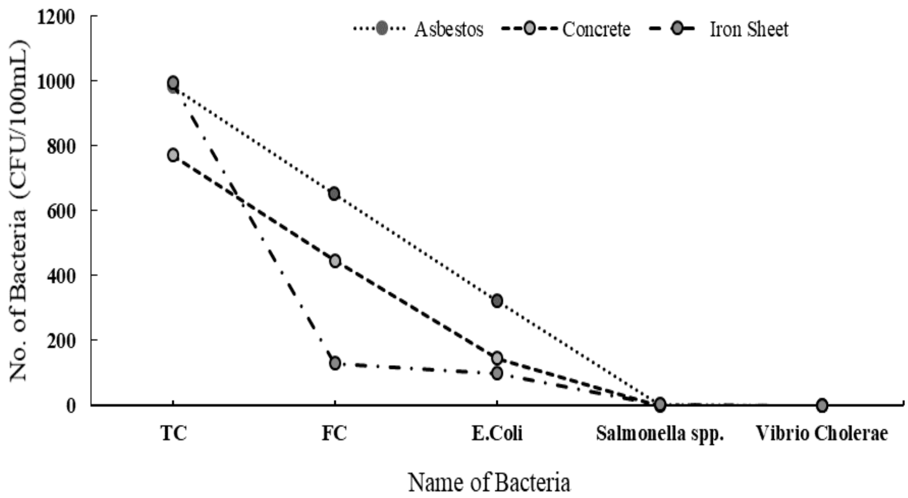

Figure 2: Contamination of bacteria in different types of roofs. Here, the X- axis represents the Types of roofing material and the Y-axis demonstrates No of Bacteria found in different water harvesting system. Besides, TC = Total Coliform; FC = Fecal Coliform

3.1.2 Heavy Metal Concentration in Different Rooftops Harvested Rainwater

The concentration of lead, chromium, cadmium, and nickel was tested, with chromium being present in a very negligible amount. The rest of the data are shown in Table 3.1. Lead levels were highest on iron sheet roofs, where the mean concentration was 12.67 ± 0.61 µg/L. Asbestos and concrete roofs exhibited mean lead concentrations of 5.067 ± 0.31 µg/L and 4.47 ± 0.4 µg/L, respectively. The mean value of Cadmium was highest on the Iron sheet roof which is 5.67 ± 0.55 µg/L and lowest on the Concrete roof which was 4.47 ± 0.15 µg/L. The mean value of nickel was found to be highest in the iron sheet roofs (86 ± 2.65 µg/L) and lowest (28.67 ± 4.93 µg/L) in concrete roofs. Chromium concentration was highest in iron sheet roofs (17.39 ± 1.59 µg/L) followed by concrete (12.4 ± 2.02 µg/L) and asbestos roofs (8.93 ± 2.53 µg/L). Cadmium concentrations in asbestos and iron sheet roofs exceeded both the WHO standard (3 µg/L) and Bangladesh standard (5 µg/L), whereas cadmium concentrations in concrete roofs only crossed the WHO level but remained within the acceptable Bangladesh standard.

Table 1: Heavy metal concentration in the harvested rainwater collected from the roof constructed with the different types of roof materials

Heavy metal	Roof type	Mean ±std. deviation (mg/L)	Bangladesh Standard (mg/L) (DPHE, 2019)
Pb	Asbestos	5.067 ± 0.31	0.05
	Concrete	8.2 ± 0.4	
	Iron sheet	12.67 ± 0.61	
Cd	Asbestos	5.63 ± 0.38	0.005
	Concrete	4.47 ± 0.15	
	Iron sheet	5.67 ± 0.55	
Ni	Asbestos	44.67 ± 5.51	0.1
	Concrete	28.67 ± 4.93	
	Iron sheet	86 ± 2.65	
Cr	Asbestos	8.93 ± 2.53	0.05
	Concrete	12.4 ± 2.02	
	Iron sheet	17.39 ± 1.59	

3.1.3 Microplastic Contamination in Different Rooftops Harvested Rainwater

Analysis of rainwater samples indicated the presence of 262 MPs particles in total at 3 distinct rooftops during the span of a single season. Furthermore, the analysis of three distinct rooftops indicated a substantial concentration of particles in concrete. The rainwater sample collected from the concrete contained the highest concentration of MPs, measuring approximately 34 MPs per liter whereas the iron sheet exhibited the lowest concentration of MPs, measuring approximately 24 MPs/L. In addition, the asbestos samples had a particle count similar to that of the concrete rainfall samples, measuring approximately 29 MPs/L. While there were no significant differences observed across the groups ($p > 0.05$), it is worth noting that concrete and iron sheet materials exhibited a highly significant difference in harvested water ($p = 0.01$).

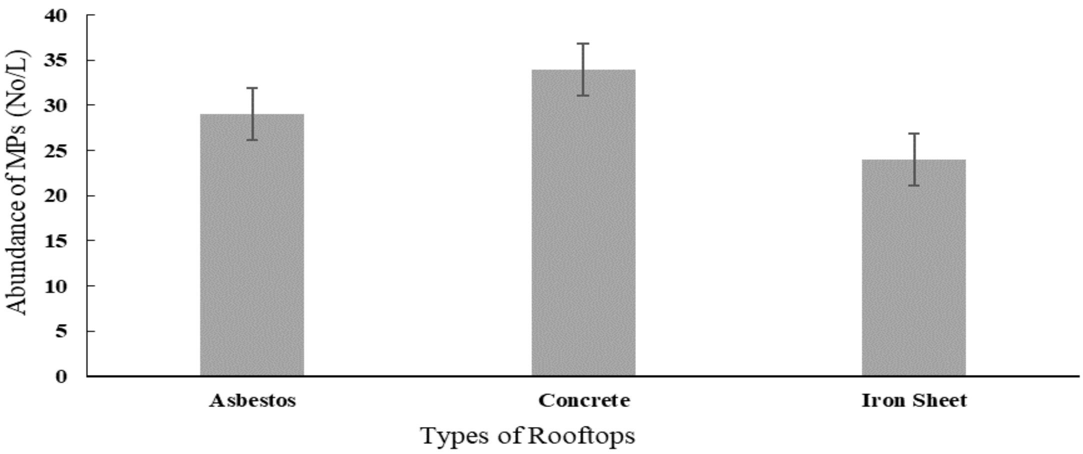

Figure 3: Number of microplastics found in harvested rainwater. The values of the x-axis denote the types of rooftops and y-axis represents the abundance of (No./L) and the error bar indicates standard deviation.

3.2 Discussion

In this study, three distinct roof types that are primarily utilized by residents of coastal areas were studied. Although rainwater is safe from microorganisms, its quality may deteriorate during the process of harvesting (Islam *et al.*, 2011). The research revealed that rainwater collected from asbestos had the most unfavorable quality, as it contained a significant presence of pathogenic bacteria as well as indicator microorganisms. The presence of pathogenic Salmonella was infrequently detected (< 1%), but Fecal Coliform and E. coli exhibited a more extensive distribution, 33% and 17% respectively. This contamination was caused by inadequate maintenance and management, and no specified frequency of cleaning was given (Rahman *et al.*, 2021). The water harvested from iron sheets had increased water properties despite its relatively low quantities of fecal matter and E. Coli since bacteria do not grow well at high temperatures (Mendez *et al.*, 2011). However, it fails to meet both the Bangladesh standards and the World Health Organization (WHO). Moreover, the highest mean concentrations of heavy metal were found in iron sheet roofs. Cadmium concentrations in two samples exceeded WHO and Bangladeshi limits, possibly due to atmospheric precipitation or leaching from metallic roofs and storage tanks (Anabtawi *et al.*, 2022). Yaziz *et al.* (1989) found lead concentrations in rainwater catchments were 4 times higher than WHO guidelines, possibly due to particulate lead "wash-out" effects in the atmosphere. Lead levels in potable roof-collected rainwater in Auckland, New Zealand, were only exceeded by iron sheet roofs (Simmons *et al.*, 2001). Lead levels in primary schools in Mongla, Bagerhat were 8 times higher than the highest concentration

(Islam *et al.*, 2019). However, the combustion of coal or wood for cooking may be responsible for the excess amount of cadmium levels in asbestos and iron sheet roofs.

4. CONCLUSIONS

This is the pioneer study in Bangladesh that investigated the effectiveness of roofing material in harvesting rainwater for drinking purposes in the context of microbial, heavy metal and microplastic contamination. In this study, iron sheets had the fewest bacterial and microplastic contamination, while asbestos had increased contamination. Meanwhile, concrete roofs had medium concentrations of bacteria. All samples violated Bangladesh's drinking water standards, potentially posing health risks. Moreover, iron sheet roofs have the highest lead concentrations, exceeding WHO standards but not Bangladesh standards. Cadmium concentrations were higher in asbestos and iron sheet roofs, while nickel levels were higher than WHO but lower than Bangladesh standards. Asbestos roofs had a lower rate of contamination. This study also suggests that, if the user wants to fulfill the drinking water standards of Bangladesh, any rainwater collected from the tested roofing materials would need to be treated. To maintain the quality of water, a procedure for design and construction, frequent hygienic monitoring, and maintenance of harvested rainwater should be developed. Further study should be carried out to determine the source of the contamination in rainwater.

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