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Case Report

Sediment Deposition within Rainwater: Case Study Comparison of Four Different Sites in Ikorodu, Nigeria

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Abstract: Building roofs represents a critical pathway for sediment mixing with rainwater. This study aims to explore the correlation between roof-top deposited sediment matter in the different areas of the Ikorodu Local Government Area in Lagos, Nigeria. The deposition rate on the roof was studied for 34 weeks in total (i.e., 17 weekly analyses in the rainy season and 17 weekly analyses in the dry season). The total deposition was collected by a 10 inch funnel and directed into a 5 L container, which was partially filled with sterilised water. The roof-top deposition in four different areas was inspected and analysed. The four areas were selected based on the levels of sanitation and vegetation. The experimental results showed that the enumerated total depositions in different areas were higher in the dry season than the rainy season, with the highest deposition occurring in the Harmattan period. The data obtained from this study have evidenced that the contamination from roof-harvested rainwater can mainly be attributed to atmospheric deposition. Another key factor was the hygiene and sanitation of the harvesting areas, including the gutter, pipes and proximity to animal faeces.

Keywords: dry season; rainwater storage; rainy season; sanitation

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1. Introduction

Sediments are described as aggregations of inorganic or organic materials that can be transported by ice, water and wind. They can exist in the form of clay to coarse sand under different flow and atmospheric conditions, as extensively studied in various literature [1–5]. In natural and man-made terrains, the sediment transportation can be significant, and its sources are complex and varied [6–8]. This further complicates the effort to retain clean water for consumption or other usages. In the effort to obtain clean and sediment-free drinking water resources, the least developed areas in the world still suffer from a lack of sanitation facilities and hence adequate access to drinkable water. In addition, 90% of these people in the rural areas from multiple developing countries practice different forms of open defecation [9–13].

Several diseases have been associated with poor sanitation facilities. These diseases include diarrhoea, vomiting, nausea, cryptosporidiosis, pneumonia, typhoid, worm infestations and ascariasis. Additionally, they can cause deteriorated physical fitness, diminished physical growth and an impaired mental function, especially among children under the age of five [10,14–18]. Sunnu et al. [10] further reported that approximately 4000 children die daily, mainly due to diarrhoea, resulting from a lack of functional sanitation facilities, the ingestion of unsafe water and poor hygiene practices.

Studies such as [19,20] have proven that bacteria are associated with sediment matter or suspended solids. These atmospheric sediment depositions may be further influenced by different local environmental features. Such features can include land use activities, the soil texture, wind speed, vegetation, vegetative residue, surface roughness, particle aggregate size distribution, soil moisture and rainfall [7,21]. In this study, a set of experiments were conducted to determine the characteristics of sediment matter from the atmosphere that settles in the stored rainwater. It investigated the rates of deposition of sediment matter from four different areas with different local features. Through this study, the suitability of storing rainwater for potable and other uses will be explored, thus providing insight into the potential dangers of such practice.

2. Study Area

The investigated area is situated in Ikorodu of Lagos, Nigeria. Ikorodu is located in the Northern part of Lagos, approximately at a longitude of 3°30′ east of the Greenwich meridian and latitude of 6°36′ north of the Equator [22]. The chosen area is both highly dependent on rainwater, especially during the rainy season, and fast-developing compared to other areas within Lagos [23,24]. During this study, the total atmospheric deposition was measured in four areas. These areas are shown in Figure 1a and are located within a 2 km radius to ensure the most similar weather pattern. The details of each area's surroundings can also be found in Figure 1b–e. These four areas are characterised by the following descriptions (locations of each area are presented in Figure 1a):

Area 1: Good sanitation with a high potential for sediment deposition (unpaved, with small amounts of vegetation);
Area 2: Good sanitation with a low potential for sediment deposition (paved, with large amounts of vegetation);
Area 3: Poor sanitation with a high potential for sediment deposition (unpaved, with small amounts of vegetation);
Area 4: Poor sanitation with a low potential for sediment deposition (paved, with large amounts of vegetation).

(**a**)

Figure 1. *Cont.*

(**b**) (**c**) (**d**) (**e**)

Figure 1. (**a**) Location of the four study areas on a Google map (source: Google Earth, 2020). (**b**–**e**) Surroundings of Areas 1–4, respectively.

To achieve the goals of this pilot study, a building was carefully selected in each of these areas to ensure representative samples. The percentage of paved area in each of the four locations was calculated by Equation (1). The calculation was conducted for the coverage of 10 m around the selected building in each of the four areas. This perimeter choice was made to ensure easy access to the surrounding houses and at the same time, to make sure that they had the same features (i.e., similar paved area and sanitation). Furthermore, good sanitation in this section refers to the safe disposal of human urine, faeces and waste; while poor sanitation refers to their unsafe disposal around the studied site.

$$\text{Percentage of paved area} = \frac{\text{Paved area in 10 m surrounding selected building}}{\text{Total area in 10 m surrounding selected building}} \times 100\% \quad (1)$$

3. Materials and Methods

3.1. Total Deposition

The four chosen buildings are situated in open areas, with the least amount of interference from other buildings and trees. Furthermore, they are not close to any upwind or downwind source, as similar determination criteria have also been used by [25,26]. Total atmospheric deposition was measured in each area using a 10″ plastic funnel leading to a 5 L container, through the method suggested by [27]. The plastic containers were placed at roof level, without any form of obstruction or over-hanging trees (Figure 2). The depositions were measured in the four areas for 34 weeks throughout the dry and rainy seasons, from mid-November to March and April to July, respectively. These plastic containers and funnels were washed with sterilised water before the beginning of all the weekly samplings. This was done to prevent the introduction of external contaminants into the water samples. The samples taken were analysed every week. The total deposition was then calculated using Equations (2) and (3).

$$\text{Total Solids (g)} = (\text{Residue} + \text{dry filter})\ (\text{g}) - \text{dry filter (g)} \quad (2)$$

$$\text{Total deposition rate}\left[\text{g}/\left(\text{m}^2\cdot\text{week}\right)\right] = \frac{\text{Total Solids (g)}}{\text{Total Funnel area }(\text{m}^2) \times \text{ Period of exposure (week)}} \quad (3)$$

Figure 2. 10-inch funnel attached to a 5 L plastic container for measuring total depositions.

3.2. Total Suspended Solids (TSS)

The Total Suspended Solids (TSS) were determined using the vacuum filtration device, which has also been used in other studies [28–30]. The steps used to determine TSS in the water samples are as described by the standard methods in [31].

3.3. Net Deposition Rate

The net deposition rate was mainly measured during the dry season, when limited or no rain events occur. Several tiles with dimensions of 80 cm × 60 cm were taped to the roof for 3, 7, 14, 28, and 56 days. The sheets were taped to the roof to avoid toppling over. The method involved fixing galvanised corrugated sheets onto the roof for the above periods and measuring the accumulated deposit. The taped tiles fitted perfectly to the roof, while the galvanised corrugated sheets were washed thoroughly with sterilised water before being fixed. Cleaning of the tile was done to prevent adding external contamination in the set up.

After removing the tape from the sheet, it was placed in a box with a lid (to avoid the depositions from being blown away), and was gently taken to where it was rinsed with cooled sterilised water to ensure that all of the deposits were collected. The water obtained after rinsing the tile was taken to the laboratory for analysis in a cooler of ice. The net deposition rate was calculated by Equations (2) and (3).

4. Results and Discussion

4.1. Total Depositions in the Four Areas

This section presents the results for the total deposition experiments in the four studied areas. The full results for this experiment are shown in Figure 3, where the results from week 1 to 17 represent the depositions that occurred in the dry season (i.e., from November to March), while subsequent weekly results represent deposition data collected during the rainy season (i.e., from April to July). Table 1 shows the range and average of the weekly depositions in the areas. The total depositions (in $g/(m^2 \cdot week)$) of sediment matter on the selected building's roof-top in locations 1, 2, 3 and 4 ranged from 8.15 to 22.42, 2.77 to

12.58, 13.05 to 28.6 and 5.21 to 15.51 g/(m^2·week), respectively, across both seasons (dry and rainy weeks). On the other hand, the averages of their respective total depositions were 12.84, 5.33, 17.90 and 8.05 g/(m^2·week). The analysis demonstrated that Areas 2 and 4 have much lower depositions compared to Areas 1 and 3. This proved that paved areas with good amounts of vegetation significantly reduce sediment depositions compared to the sanitation factor. Area 2, with good sanitation, a paved area and plenty of vegetation, gave the best outcome, with the lowest deposition level. Therefore, it is suggested that the best practices for reducing the atmospheric deposition in stored rainwater are paving the surroundings of houses, i.e., front and backyards, or planting vegetation, which is still un-common in rural African areas.

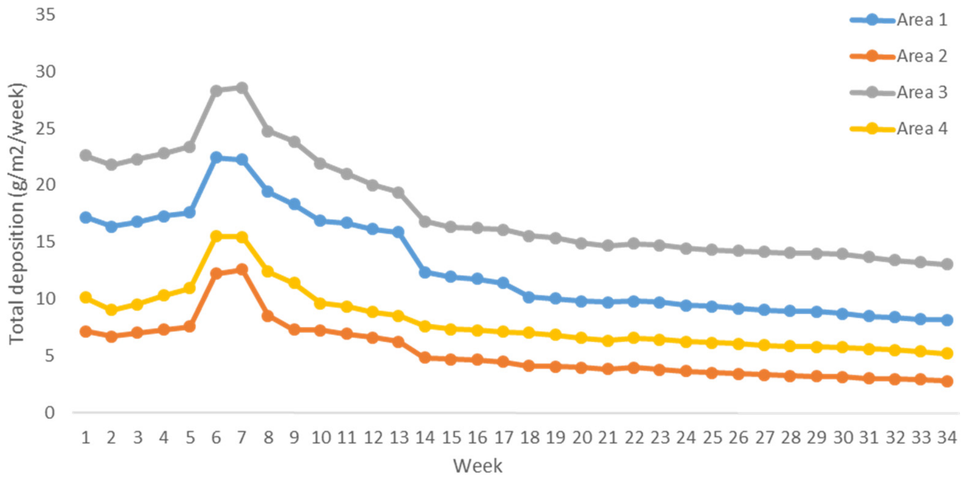

Figure 3. Total depositions in the four areas in both dry and rainy seasons.

Table 1. Depositions (in g/(m^2·week)) in the four areas in both rainy and dry seasons.

	Area 1	Area 2	Area 3	Area 4
Minimum	8.15	2.77	13.05	5.21
Maximum	22.42	12.58	28.6	15.51
Average	12.84	5.33	17.9	8.05

4.1.1. Total Depositions in the Dry Season

In the dry season, the total depositions in Areas 1, 2, 3 and 4 ranged from 11.41 to 22.42, 4.48 to 12.58, 16.08 to 28.6 and 7.12 to 15.51 g/(m^2·week), respectively, whereas their corresponding averages were 16.51, 7.19, 21.54 and 10.02 g/(m^2·week) (Table 2). The results illustrated that the depositions were the highest during the Harmattan period (see week 6 and 7 of Figure 4), while the lowest values were observed in the dry season at the end of the season (week 17 of Figure 4). The results illustrate that the unpaved areas exhibited more dust depositions compared to the paved areas in the dry season, which will further deteriorate sedimentation.

Table 2. Depositions (in g/(m^2·week)) in the four areas in the dry season only.

	Area 1	Area 2	Area 3	Area 4
Minimum	11.41	4.48	16.08	7.12
Maximum	22.42	12.58	28.6	15.51
Average	16.51	7.19	21.54	10.02

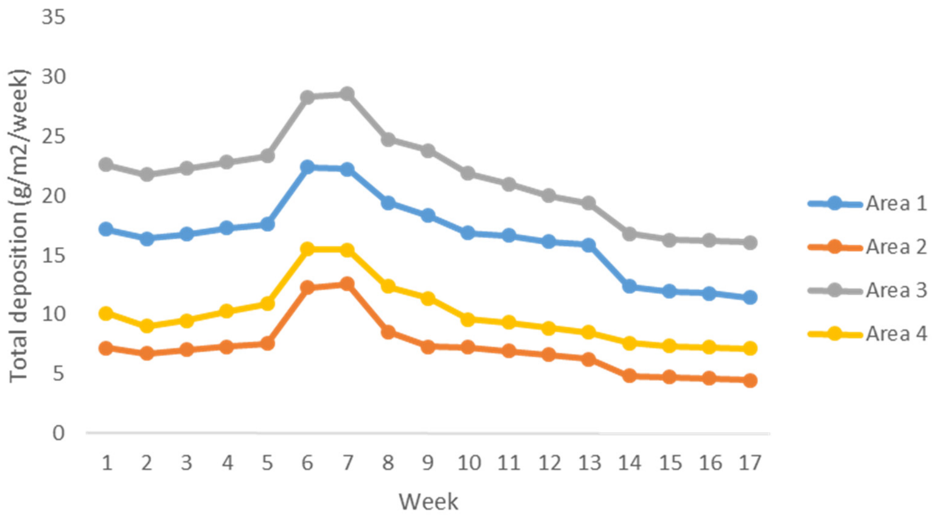

Figure 4. Total depositions in the four areas in the dry season only.

4.1.2. Depositions in the Rainy Season

Table 3 presents data for the rainy season, where the total depositions in areas 1, 2, 3 and 4 ranged from 8.15 to 10.18, 2.77 to 4.12, 13.05 to 15.53 and 5.21 to 7.01 g/(m^2·week), respectively, and their corresponding averages were 9.18, 3.46, 14.27 and 6.08 g/(m^2·week). Observation of the data from the rainy season further indicated that the depositions were the highest at the beginning of week 18 (Figure 5) and lowest towards the end of the season (week 34 of Figure 5). Furthermore, a continuous reduction in the deposition was observed amid rain events. In comparison, the results in Tables 2 and 3 conclusively revealed that the total deposition of sediment matter in the dry season was higher than in the rainy season due to the fact that the dry season can promote atmospheric deposition. This finding further emphasises the importance of cleaning the storage container or tank after each dry season (i.e., through the practice of first-flush) to maintain a low sediment level in the collected rainwater.

Table 3. Depositions (in g/(m^2·week)) in the four areas in the rainy season.

	Area 1	Area 2	Area 3	Area 4
Min	8.15	2.77	13.05	5.21
Max	10.18	4.12	15.53	7.01
Average	9.18	3.46	14.27	6.08

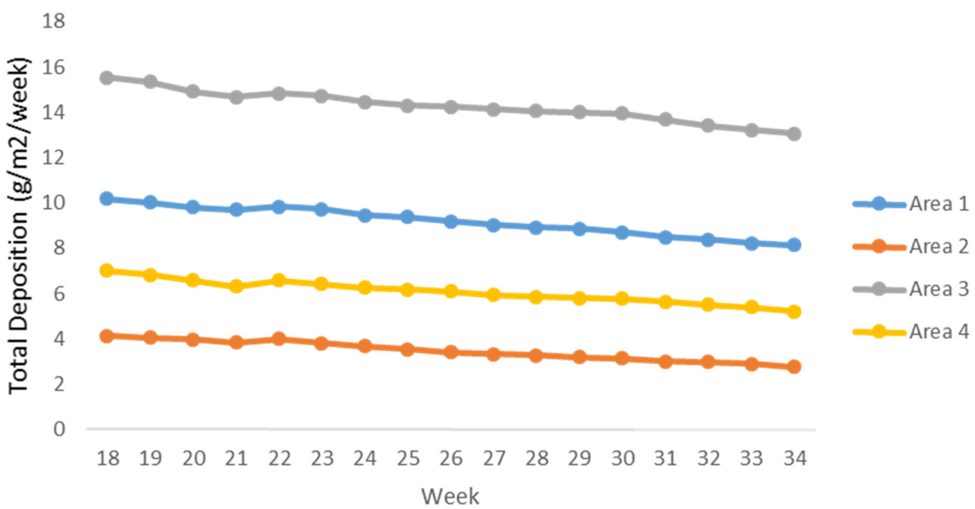

Figure 5. Total depositions in the four areas in the rainy season.

4.1.3. Discussions and Analyses

In Nigeria, dust particles can originate from various sources, including Harmattan dusts, industrial activities, constant bush burning, and traffic on unpaved (untarred) roads [32]. The results obtained from the proposed experiments evidenced that the deposition of particles on roofs varies for different areas during different seasons. The peak total depositions across all seasons were 22.26, 12.58, 28.6 and 15.45 g/(m^2·week) for Areas 1, 2, 3 and 4, respectively. This was observed in the 7th week of the analysis, which was within the first 2 weeks of January (Figures 4 and 5). The peak deposition in the Harmattan period has been resulted from the cold dry and dust-laden trade wind, which blows over the sub-regions of West Africa. The Harmattan period usually presents weather conditions which are desert-like, where it reduces the humidity, disperses clouds cover, thwarts the formation of rainfall and occasionally forms huge clouds of dust storms or sandstorms which can severely limit visibility and obstruct the sunlight [9,10]. The agricultural use of lands adjacent to the desert dust source and the drought in the Sahel can also be significantly associated with an increase in the dust source strength from the Sahara Desert [10,25]. This further explains and supports the hypothesis that unpaved areas will produce more depositions than paved areas.

4.2. Accumulation of Sediment Matter over Time

To investigate the accumulation of deposition over time, the net depositions were correlated with different days of exposure to weather. These investigations included short-term and long-term net depositions. The short-term deposition included three day and weekly net depositions, while the long-term deposition included fortnightly, monthly, and two-monthly net depositions. Figure 6 illustrates the results for both long- and short-term net depositions that were investigated for the dry season. Since rain events in the rainy season washed away the deposition, only the short-term result was collected for the rainy season. The results showed that a strong positive correlation of 0.92 exists between the accumulated net depositions and the period of exposure (Figure 6), where a linear correlated equation can be deduced as Equation (4). The well-correlated data for the accumulated deposit and the period of exposure proved the direct influence of the period of atmospheric exposure on the deposition. Moreover, the linear relationship presented for both short-term and long-term net depositions indicated that no external anthropogenic factors impacted the collected data, which was an outcome of the carefully selected sampling locations.

$$\text{Accumulated Net Deposit}\left(\mathrm{g}/\mathrm{m}^2/\mathrm{day}\right) = 0.151 * \text{Period of Exposure (days)} + 0.1023 \quad (4)$$

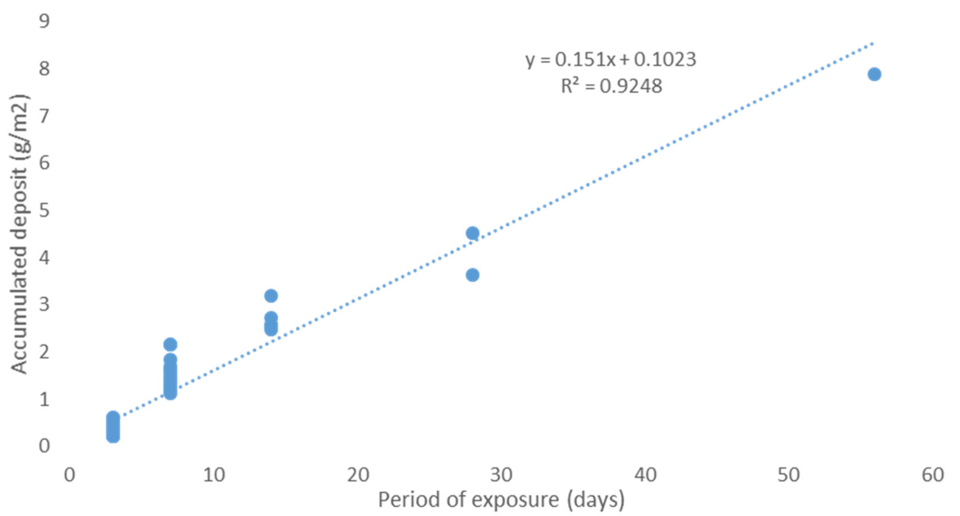

Figure 6. Correlation between the accumulated deposit (g/m^2) and period of exposure (days) for both the rainy and dry season.

5. Conclusions

This paper estimated the rate of sediment matter deposition on buildings' roof-tops in different environments. It can be concluded that the deposition of sediment matter in an area is influenced by local environmental factors. The local environmental factors investigated in this study were the types of sanitation and the different potentials for sediment deposition (i.e., via paved area and vegetation). The results on the total depositions in the four investigated areas were higher in the dry season compared to the rainy season due to the higher deposition experienced in the Harmattan period. It was also found that the unpaved areas (i.e., Areas 1 and 3) produced more depositions than areas that were paved (i.e., Areas 2 and 4). It has been further revealed that the contamination of the roof-harvested rainwater can mainly be attributed to the atmospheric depositions of sediment matter on the building's roof-top, but other factors, including sanitation of the roof catchment (which includes the gutter, pipes and proximity to animal faeces), may also have contributed to it.

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