Tropical Built Environment Journal. Volume 10, No. 2, 61-87, 2024 www.tbejournal.com
ISSN: 1118-1790

Assessing Quality of Harvested Rainwater from Different Roofing Materials in Gwagwalada, Federal Capital Territory, Nigeria

By

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Abstract

This study assessed the physicochemical and bacteriological characteristics of rainwater harvested from five different roof materials galvanized zinc roof (GZ), stone coated roof (SC), asbestos roof (AS), Aluminum roof (AL) and thatch roof (TH), with a control sample (CT), which was collected from an open space, all in Gwagwalada, Federal Capital Territory of Nigeria, at onset and peak of wet season. Results showed that the mean values of the analysed parameters generally had higher concentrations for samples collected at the onset of rain. From the laboratory analysis and spatial interpolation, the physicochemical parameters showed no much detectable variation pattern of water quality amongst the selected roof types. However, samples from AS and TH roofs showed higher contamination level in EC, Turbidity, TDS, TSS, Nitrate, Sulphate and Chloride. TH roof water samples had the highest concentration of the biological parameters, while AL roof water samples had the least concentration of same parameters in both sampling periods, with Enterobacter and Klebsiella absent in the peak period samples from AL roof. The physicochemical parameters were within W.H.O. permissible limits but the bacteriological analysis showed evidence of contamination. For both the onset and peak of the wet season, the ANOVA results indicates that there is no significant variation in the concentration of the tested parameters across the different roof types. Having the least concentration for most of the analyzed parameters, samples from AL roof proved to be most suitable. It is recommended, among others that all harvested rainwater should be adequately treated before consumption.

Keywords: Rainwater; Roof materials; Water quality; Contamination; Onset; Peak

1.0 Introduction

Urbanization and the ever-increasing population have necessitated the dependence on harvested rainwater as a source of both potable and non-potable water in many developing countries of the world, especially in those areas where precipitation is recorded for most part of the year. Rainwater harvesting (RWH) is an old water provision technique that plays an important

role in meeting the increasing water demand. It is a technique of collecting, storing and conserving rainwater for subsequent use. Rainwater from surfaces such as road surfaces, rooftop terraces, and land surfaces is stored in underground or surface storage tanks for use during periods of scarcity (Campisano *et al*., 2017; Rawan *et al*., 2022). The choice of rainwater as an alternative to other water sources is due to its natural state as it comes from the atmosphere and void of contaminants in itself, with no additional cost incurred in its collection. In many parts of the world today, it can either be the only source of water for the household, or more commonly a supplementary supply to ease the burden of water collection from other sources (Ikhioya *et al*., 2015).

Harvesting of rainwater has become essential in order to handle the extreme crisis of fresh water in many parts of sub-Saharan Africa including Nigeria. One of the premium ways of harvesting rainwater in many areas is by using the house rooftops as the catchment (Bernard and Joyfred, 2020; Bañas *et al*., 2023). However, an important aspect to be considered regarding harvested rainwater is its quality. The quality of roof harvested rainwater is affected by several factors such as environmental contamination, roofing material, the existence of dirt and birds or rodent faeces on the rooftop, as well as the condition of the storage system for collecting rainwater (Igbinosa and Aighewi, 2017; Meera and Ahammed, 2018). Studies have shown that roofs can be a serious non-point source of rainwater contamination (Hamilton *et al*., 2018; Thomas and Kouame, 2019; Rawan *et al*., 2022; Nicholas and Ukoha, 2023). Contamination of rainwater from roof surfaces can come from two main sources: particles can accumulate on the roof surface either from direct atmospheric deposition or from overhanging foliage or bird and rodent debris; alternatively, the roof material itself continuously degrades and can contribute both particulate matter and dissolved chemicals to runoff water (Thomas and Kouame, 2019). While the former is largely site-specific, the impact of different roof materials is fairly consistent regardless of location.

Studies by Saidu *et al*. (2021), Tenebe *et al.* (2022) and Rawan *et al.* (2022) have shown that roof materials such as copper flashings, clay or concrete tiles, zinc sheet, galvanized metal roofs and asbestos are often associated with the leaching of trace elements, detected in the dissolved form in the runoff itself and adhered to the particulate matter washed from the roof. Akintola and Sangodoyin (2011), Ezemonye *et al*. (2016) and Morka

(2022) in their research in Ibadan, Benin and Abraka respectively, also reported presence of major microbiological contaminants such as *Escherichia coli, Klebsiella sp* and *Pseudomonas fluorescence* in domestic roof-harvested rainwater. Water pollution caused by bacterial contamination is a serious problem due to the potential for contracting diseases from pathogens.

Rainwater harvesting has become popular as a sustainable source of water in Gwagwalada, Federal Capital Territory, with many not knowing the quality of the water and its effects on their health. Gwagwalada, the study area, is saddled with the problems of increasing population, water scarcity as well as insecurity. The provision of pipe-borne water by the Federal Capital Territory Water Board has been erratic, coupled with cases of kidnapping and banditry which has prevented many people from going to far places in search of water. This has caused many residents to depend on harvested rainwater for their domestic activities. However, there are possibilities of waterborne diseases arising from the physical, chemical, and microbial contamination of the water. This study therefore carried out the qualitative assessments of roof-harvested rainwater in the study area in order to determine their physical, chemical and biological properties.

2.0 Materials and Methods

2.1. Study Area

Gwagwalada is one of the six Area Councils of the Federal Capital Territory (FCT) of Nigeria. It is located between latitude 8°50'N and 9°00'N and between longitude 6°50''and 7°00'E, with an altitude of about 400 - 600m and a total land area of 1,043km^2. Being part of the Federal Capital Territory (FCT), Gwagwalada falls under the tropical sub-humid climate with distinct dry and wet season with high temperature throughout the year (Madaki and Jibrin, 2014; Makwe and Ahmad, 2017). The wet season commences in late March or early April and lasts to mid-October while dry season starts from late October to March. The mean annual rainfall varies from 1145mm to 1631mm (Hassan, 2002), with 60% of the annual rainfall received during the months of July, August and September.Temperature in Gwagwalada records its highest value during the month of March which is between 39°C and 40.1°C and its lowest in December which ranges from 17.2°C to 19.1°C (Madaki and Jibrin, 2014). Gwagwalada is well drained through a series of small streams that convey water

from all parts of the town to River Usuma, a tributary of River Gurara, the largest river within Gwagwalada (Adakayi, 2000). The water in these rivers are heavily polluted due to several domestic, industrial and farming activities around them (Balogun, 2001).

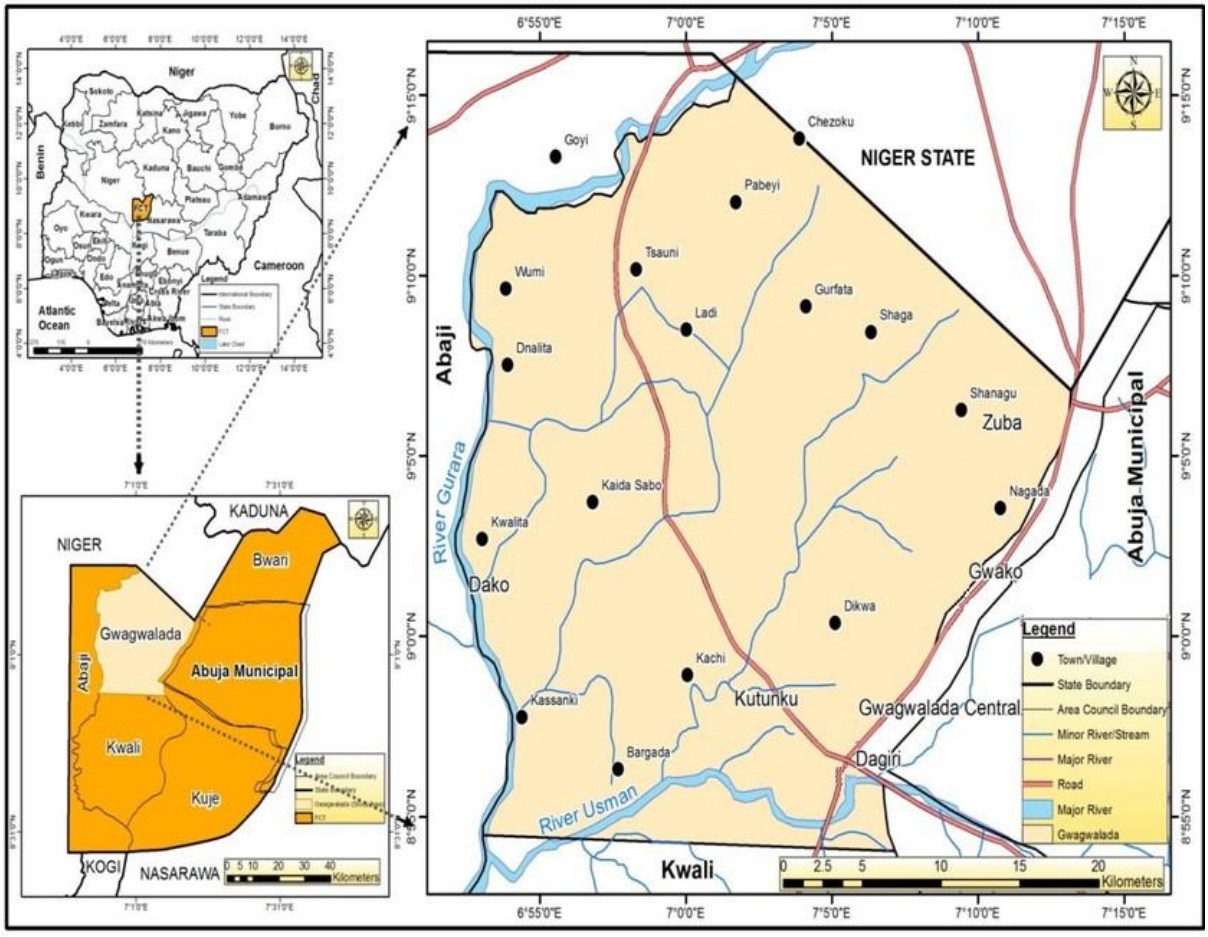


Figure 1: Map of the Federal Capital Territory showing Gwagwalada Area Council
Source: Researcher's field work, 2023

2.2. Sample Collection

Rainwater samples were collected from five locations with two replicates from each of the five different roofing sheet/materials namely: galvanized zinc roof (GZ), stone coated roof (SC), asbestos roof (AS), Aluminum roof (AL) and thatch roof (TH). A control sample (CT) was harvested in an open field without contact with any catchment roofing surface making the sixth samples. The samples were obtained randomly where the specified roof types were found in the study area. The rainwater samples were collected during rainfall events for two sampling periods: at the onset of the rainy season (April, 2022) and at the peak of rainfall (July, 2022). A total of Thirty-two (32) samples were collected from

the different roof types and the control for the two sampling periods. The samples were obtained in plastic bottles which were pre-cleaned with deionized water and rinsed with the rainwater samples before use (Makwe *et al*., 2020; Makwe and Madu, 2021). The samples were collected from a height of about 1-2m above the ground to avoid possible contamination through splashes from the ground surface. After collection, the samples were placed in cooler boxes filled with ice to keep them at about 4°C and transported to the laboratory for analysis. In addition, the coordinates of each of the sampling locations were taken using a Global Positioning System (GPS) device and these were inputted into the ArcGIS environment so as to generate maps showing the spatial variation of the parameters considered.

Table 1: Sampling Frame

Location	Roof Type	Code	Coordinates		
			N	E	Elevation
Gwagwalada Phase 1	Stone coated roof	SC	08.9458	007.0858	197
Gwagwalada Phase 2	Asbestos roof	AS	08.9475	007.0732	212
Gwagwalada Phase 3	Aluminum roof	AL	08.9557	007.0711	217
Dukpa	Thatch roof	TH	08.9894	007.0820	218
Hospital Road	Galvanized zinc roof	GZ	08.9935	007.0772	197
Dukpa	CONTROL	CT	08.9933	007.0773	213

3.0 Laboratory Analysis

3.1 Physicochemical Analysis

All analyses were done in triplicates using standard methods for water quality analysis. Non conservable parameters such as pH, turbidity and electrical conductivity were determined in-situ. The pH was measured with a pH meter previously calibrated with a buffer solution with the temperature reading while conductivity was measured with a conductivity meter calibrated with potassium chloride solution. Other physicochemical properties such total dissolved solid, total suspended solids, total hardness, nitrate, sulphate and chloride were analysed following standard procedures as outlined in APHA (2012). The presence of heavy metals (iron, aluminum, lead, zinc) were determined using Atomic Absorption Spectrophotometer (AAS, Buck Scientific 210 VGP).

3.2 Microbiological Analysis

Frequently, concentrations of pathogens from fecal contamination are small, and the number of different possible pathogens is large. As a result, it is not practical to test for all pathogens in every water sample collected. Instead, the presence of pathogens is determined with indirect evidence by testing for an "indicator" organism such as coliform bacteria (Motlagh and Yang, 2019; Richiardi *et al*., 2023). Coliforms come from the same sources as pathogenic organisms and are relatively easy to identify. They are usually present in larger numbers than more dangerous pathogens. As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present.

The water samples were analysed for the presence and densities of coliforms (faecal and non-faecal) such as Enterobacter, Klebsiella and *E. coli*. Membrane filtration technique was conducted for enumeration of total viable and coliform counts (Vunain *et al.,* 2019; Morka, 2022). A pore sized 0.45 µm of a sterile membrane filter (small enough to retain the indicator bacteria to be counted) was employed for the filtration of 100 ml of each of the harvested rainwater samples. The paper filter was mounted on an already prepared or solidified Membrane Lactose Glucuronide agar plate in inverted form. The plates were then incubated at 37°C for 20 hrs and at 44.5°C for 24 hrs respectively for the counts of total coliform and thermo tolerant faecal coliforms (Makwe and Chup 2013). The Green and yellow clusters were recorded as total coliform whereas plates observed as green and yellow clusters were recorded as thermo-tolerant faecal coliforms using a colony counter reported as Colony Forming Units (CFU) per 100ml. Gram staining reactions, morphological test, and relevant biochemical techniques were employed for identification.

3.3 Quality Assurance Procedure

Special precautions that were considered for quality assurance includes: all reagents used were of standard analytical grade and sample for metal analyses were preserved with 3 ml concentrated HNO_3 per litre from the field. Samples for sulphate were refrigerated and analysed within 24 hours. All plastics and wares used were washed, pre-cleaned with deionized water and rinsed with the rainwater samples before use.

3.4 Data Analysis

The results obtained from the laboratory analyses of the rainwater samples were compared with the World Health Organisation (WHO) standards for drinking

water quality. The Analysis of Variance (ANOVA) statistics was used to test for variation in the concentration of the tested parameters in the water samples from the different roof materials for each sampling period. Furthermore, the spatial variation in the concentration of the tested parameters across the different roof types were also analysed using the Inverse Distance Weighting (IDW) interpolation method.

4.0 Results and Discussion

The results of the laboratory (physicochemical and microbial) analysis of the rainwater samples collected at the onset of the rainy season (April) and peak of rainy season (July) for the different roof types are presented in Tables 3, 4, 5 and 6.

Table3: Physicochemical Parameters of Harvested Rainwater Samples (Onset of Wet season)

Parameter	Statistics	SC	AS	AL	TH	GZ	Control	WHO
pH	**Range**	5.3-6.6	5.1-6.3	5.0-6.4	5.6-6.8	5.0-6.5	6.7	6.5-8.5
	Mean	6.0	5.7	5.5	6.1	5.8.		
	SD	0.47	0.49	0.54	0.48	0.60		
EC (µS/cm)	**Range**	222-284	467-548	244-283	496-582	378-405	383	1000
	Mean	249	501.3	263.5	536.5	389		
	SD	23.60	34.23	16.77	37.98	10.61		
Turbidity (NTU)	**Range**	0.6-1.1	0.5-2.1	0.4-1.2	1.1-2.6	04-1.8	0.2	5
	Mean	0.85	1.2	0.8	1.8	1.03		
	SD	0.18	0.62	0.29	0.55	0.51		
TDS (mg/l)	**Range**	18.5-21.8	48.5-62.6	22.2-30.5	40.3-58.5	34.2-38.3	6.3	1000
	Mean	19.70	54.60	26.18	48.55	35.68		
	SD	1.27	5.36	3.04	6.75	1.81		
TSS (mg/l)	**Range**	0.09-0.12	0.8- 1.20	0.04-0.11	0.8-1.3	0.05-0.09	0.04	600
	Mean	0.10	0.77	0.08	0.98	0.07		
	SD	0.01	0.38	0.03	0.20	0.02		
T/Hardness (mg/l)	**Range**	12.6-14.0	22.3-24.0	14.5-16.3	11.2-13.1	18.9-19.4	7.2	100-300
	Mean	13.23	23.10	15.48	12.03	19.10		
	SD	0.56	0.61	0.72	0.69	0.21		
Nitrate (mg/l)	**Range**	6.2-8.6	16.1-16.8	6.8-7.1	17.7-23.0	8.2-9.2	3.6	50
	Mean	7.25	16.38	6.93	19.55	8.88		
	SD	0.87	0.27	0.11	2.09	0.41		
Sulphate (mg/l)	**Range**	0.2-0.5	0.6-0.8	0.4-0.5	0.3-0-4	0.4-0.7	0.2	250
	Mean	0.38	0.70	0.45	0.33	0.55		
	SD	0.13	0.07	0.05	0.04	0.11		
Chloride (mg/l)	**Range**	3.7-4.6	8.6-9.8	7.1-8.1	4.6-5.1	7.7-8.7	1.8	200
	Mean	4.13	9.10	7.68	4.83	8.08		
	SD	0.35	0.44	0.38	0.23	0.38		
Aluminium (mg/l)	**Range**	ND	ND	ND	ND	ND	ND	0.2
	Mean	--	--	--	--	--		

	SD	--	--	--	--	--		
Iron (mg/l)	**Range**	0.02-0.03	0.04-0.06	0.06-0.09	0.02-0.04	0.19-0.22	ND	0.3
	Mean	0.03	0.05	0.07	0.03	0.20		
	SD	0.01	0.01	0.01	0.01	0.01		
Lead (mg/l)	**Range**	ND	0.001-0.002	0.00-0.001	0.00-0.001	0.00-0.001	ND	0.01
	Mean	--	0.002	0.001	0.001	0.001		
	SD	--	0.001	0.000	0.001	0.000		
Zinc (mg/l)	**Range**	ND	ND	0.0-0.01	ND	0.01-0.02	ND	5
	Mean	ND	ND	0.008	ND	0.018		
	SD	ND	ND	0.004	ND	0.004		

ND = Not Detected
Source: Author's Lab Analysis

Table 4: Biological Parameters of Harvested Rainwater Samples (Onset of wet season)

Parameter	**SC**	**AS**	**AL**	**TH**	**GZ**	**Control**	**WHO**
Total coliforms (cfu/ml)	1.8±0.3	3.8±1.0	1.2±0.3	18.2±3.1	2.75±1.1	ND	0.0
***E.coli* (cfu/ml)**	0.3±0.06	0.5±0.05	0.2±0.07	4.8±1.6	0.5±0.1	ND	0.0
Enterobacter (cfu/ml)	0.2±0.04	0.3±0.03	0.1±0.02	3.4±0.7	0.3±0.1	ND	0.0
Klebsiella (cfu/ml)	0.2±0.03	0.1±0.04	0.2±0.02	3.6±1.4	1.1±0.2	ND	0.0

Mean±Standard deviation
ND = Not Detected
Source: Author's Lab Analysis

Table 5: Physicochemical Parameters of Harvested Rainwater Samples (Peak of wet season)

Parameter	**Statistics**	**SC**	**AS**	**AL**	**TH**	**GZ**	**Control**	**WHO**
pH	**Range**	5.1-7.5	5.3-6.4	5.2-6.9	5.3-7.9	5.4-6.4	6.6	6.5-8.5
	Mean	5.7	5.6	6.0	6.0	5.9		
	SD	5.82	5.71	6.23	6.18	5.96		
EC (µS/cm)	**Range**	220-246	397-518	245-263	430-456	333-400	330	NA
	Mean	233	444	255	444.5	360.75		
	SD	10.89	57.13	7.48	11.24	30.70		
Turbidity (NTU)	**Range**	0.2-0.8	0.3-1.2	0.3-1.0	0.8-1.6	03-1.1	0.1	5
	Mean	0.48	0.75	0.65	1.18	0.73		
	SD	0.25	0.39	0.31	0.35	0.35		
TDS (mg/l)	**Range**	10.2-14.1	28.9-38.6	17.4-21.7	28.5-33.5	28.1-30.2	3.4	1000
	Mean	12.18	32.85	19.08	30.90	29.13		
	SD	1.83	4.36	1.87	2.38	0.89		
TSS (mg/l)	**Range**	0.05-0.08	0.3-0.8	0.05-0.10	0.4-0.9	0.06-0.07	0.03	600
	Mean	0.06	0.60	0.08	0.68	0.06		
	SD	0.01	0.19	0.02	0.19	0.00		
T/Hardness (mg/l)	**Range**	8.3-9.8	14.6-16.5	9.0-11.7	8.9-10.2	12.0-14.5	4.0	100-300
	Mean	9.23	15.45	10.00	9.38	13.23		

	SD	0.70	0.87	1.29	0.57	1.07		
Nitrate (mg/l)	**Range**	4.9-5.2	8.9-12.9	5.2-6-9	13.2-16.9	7.0-7.9	ND	50
	Mean	5.03	10.38	5.98	14.78	3.73		
	SD	0.13	1.85	0.72	1.58	4.32		
Sulphate (mg/l)	**Range**	0.1-0.4	0.4-0.7	0.3-0.5	0.2-0-4	0.2-0.5	ND	250
	Mean	0.23	0.50	0.40	0.33	0.38		
	SD	0.13	0.14	0.08	0.10	0.15		
Chloride (mg/l)	**Range**	2.0-2.4	6.9-7.6	4.8-7.1	3.4-4.1	6.7-6.9	0.90	200
	Mean	2.28	7.25	5.78	3.80	6.80		
	SD	0.19	0.31	1.01	0.29	0.08		
Aluminium (mg/l)	**Range**	ND	ND	ND	ND	ND	ND	0.2
	Mean	ND	ND	ND	ND	ND		
	SD	ND	ND	ND	ND	ND		
Iron (mg/l)	**Range**	ND	0.01-0.03	0.00-0.02	0.00-0.01	0.10-0.16	ND	0.3
	Mean	ND	0.02	0.01	0.01	0.12		
	SD	ND	0.01	0.01	0.01	0.03		
Lead (mg/l)	**Range**	ND	ND	ND	ND	ND	ND	0.01
	Mean	ND	ND	ND	ND	ND		
	SD	ND	ND	ND	ND	ND		
Zinc (mg/l)	**Range**	ND	ND	ND	ND	0.01-0.02	ND	5
	Mean	ND	ND	ND	ND	0.015		
	SD	ND	ND	ND	ND	0.01		

ND = Not Detected
Source: Author's Lab Analysis

Table 6: Biological Parameters of Harvested Rainwater Samples (Peak of wet season)

Parameter	**SC**	**AS**	**AL**	**TH**	**GZ**	**Control**	**WHO**
Total coliforms (cfu/ml)	0.7±0.1	1.1±0.3	0.6±0.2	7.4±2.8	1.1±0.3	ND	0.0
***E.coli* (cfu/ml)**	0.1±0.03	0.2±0.06	0.1±0.02	2.5±1.3	0.2±0.09	ND	0.0
Enterobacter (cfu/ml)	ND	0.1±0.05	ND	1.1±0.4	0.1±0.03	ND	0.0
Klebsiella (cfu/ml)	0.1±0.02	ND	ND	0.9±0.3	0.5±0.2	ND	0.0

Mean±Standard deviation
ND = Not Detected
Source: Author's Lab Analysis

4.1 Variation in Physicochemical Parameters of Rainwater Samples

The pH values for the harvested rainwater at the onset of rain (April) generally ranged from 5.0 – 6.8 across the different roof types: SC, AS, AL, TH and GZ. At the peak of rain (July), the pH value ranged from 5.1 - 6.5 across the different roof types. The mean values for pH are lower than the WHO (2017) recommended pH value range of 6.5-8.5 for drinking water (Tables 3 and 5), indicating that they are slightly more acidic than the recommended values. However, the

control rainwater sample has pH values of 6.7 and 6.6 for the onset and peak periods respectively. At both periods, the thatched roof rain water from Dukpa had the highest mean pH values (6.1 and 6.0 respectively) as shown in figure 2 and 3.

The electrical conductivity of water increases with increase in the amount of dissolved ionisable solids in the water (Iyasele *et al*., 2015; USEPA, 2023). The mean Electrical conductivity values for the harvested rainwater samples ranged from 249µS/cm, 501.3µS/cm, 263.5µS/cm, 536µS/cm and 389µS/cm for SC, AS, AL, TH and GZ roofs respectively at the onset of the wet season. These mean EC values generally reduced at the peak of the wet season. The higher values are most likely due to the presence of dust and other solids on the roofs, which dissolved in the rainwater. The samples from the stone coated roof had the lowest mean EC values for both sampling periods while the thatch roof samples had the highest mean EC values for the two season (Tables 3 and 5, figure 2 and 3). The control sample has an EC value of 383µS/cm and 330µS/cm for the onset and peak periods respectively. Water with high conductivity does not necessarily pose a risk to human health, however, the dissolved ionisable solids may cause water hardness and this may cause consumer dissatisfaction.

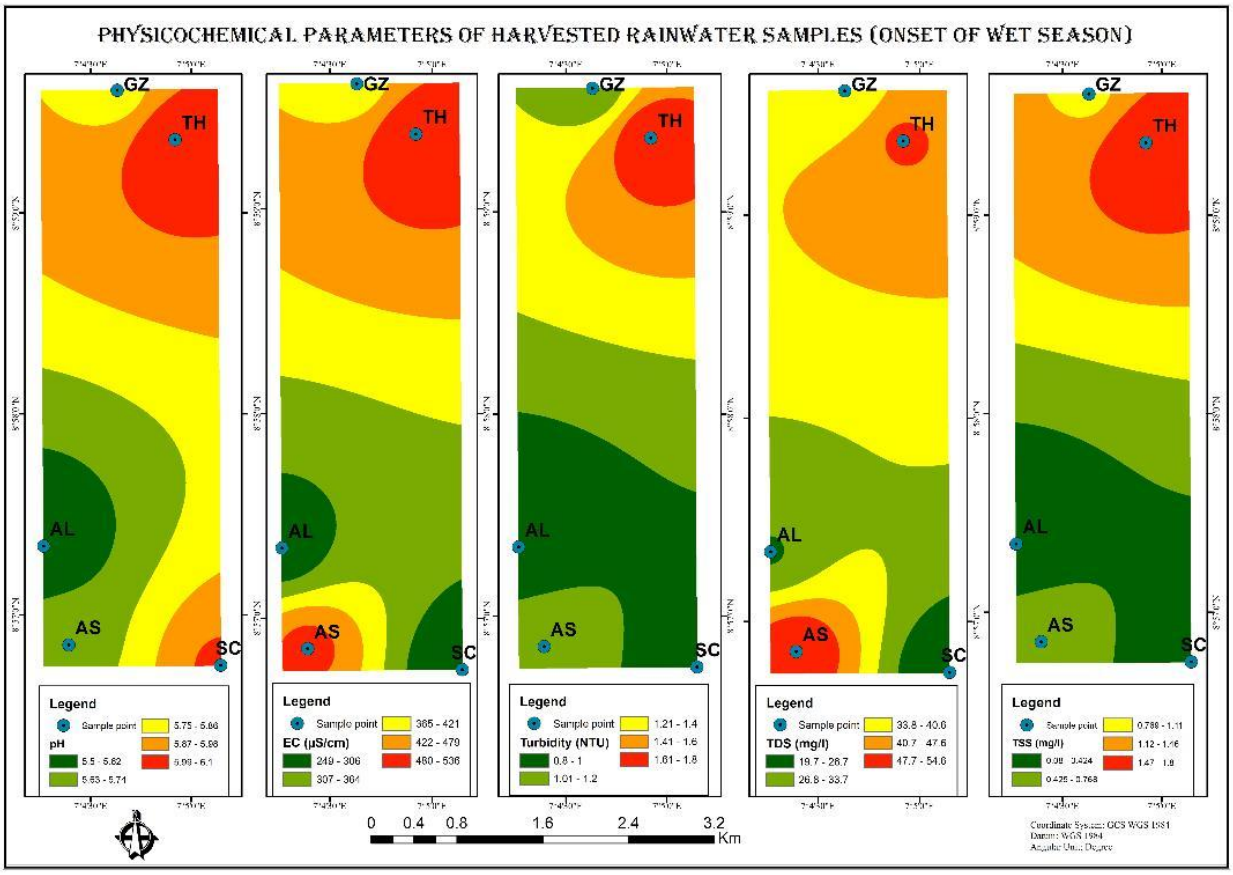


Figure 2: Spatial variation in pH, EC, Turbidity, TDS and TSS (Onset of wet season)
Source: Researcher's field work

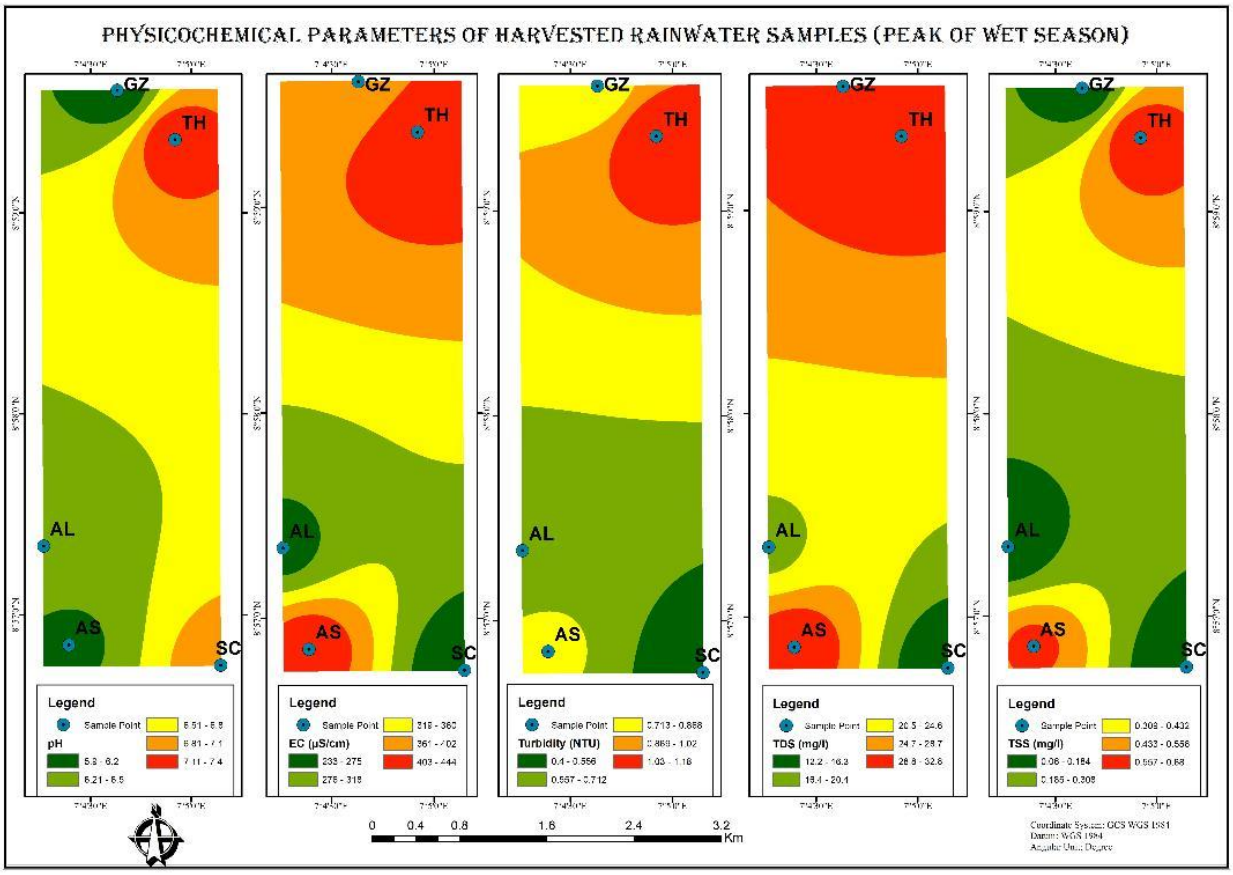


Figure 3: Spatial variation in pH, EC, Turbidity, TDS and TSS (Peak of wet season)
Source: Researcher's field work

The mean turbidity values for the harvested rainwater ranged from 0.85NTU to 1.8NTU across the different roof types at the onset of rain, while the peak period has mean turbidity values ranging from 0.48NTU to 1.18NTU for the different roof types (Table 3 and 5). The higher mean turbidity values at the onset of rain are most likely due to the presence of dust and other solids on the roofs, which dissolved in the rainwater and affected their appearance. The samples from thatch roof had the highest turbidity for the two periods (onset and peak of rain) (Figure 2 and 3). The control sample has a turbidity of 0.2NTU and 0.1NTU for the onset and peak periods respectively. The WHO established that the turbidity of drinking water shouldn't be more than 5NTU and should ideally be below 1NTU. Turbidity itself is not a cause of concern, however, when bacteria and other microorganisms persist in the water, it may adversely affect consumers health.

Total Dissolved Solids (TDS) in water is not a measure of any single contaminant. A high TDS in water may affects odour and taste. The mean TDS values for the harvested rain water samples ranged from 19.7mg/l to 54.6mg/l, for the different roof types (SC, AS, AL, TH and GZ roofs) at the onset of rain. These concentrations are however reduced during the peak period ranging from 12.18mg/l to 32.85mg/l, with SC roof having the lowest mean TDS values and AS roof having the highest TDS values (Table 3 and 5, Figure 2 and 3). The reduction in the mean TDS values during the peak rain period is most likely because the dissolvable solids on the roofs have been substantially washed off. The control samples have TDS values of 6.3mg/l and 3.4mg/l for the onset and peak rain periods. All the water samples have TDS value within the WHO (2017) recommended limits of 500-1000.

Total Suspended Solids (TSS) could be anything that floats or suspends in water including sand, sediments, or organic matter such as animal faeces, plant matter, etc. The mean values of total suspended solids for the harvested rainwater ranged from 0.07mg/l to 0.98mg/l for the onset period, whereas at the peak of rainfall, these mean values reduced and ranged from to 0.06mg/l to 0.68mg/l across the different roof types. Rainwater from thatched roof has the highest mean TSS values for both onset and peak periods of collection with 0.98mg/l and 0.68mg/l respectively (Table 3 and 5, Figure 2 and 3). The reduction in the mean TSS values at the peak of rainfall is due to the fact that most of the solid materials on the different roofs has been washed off by the rain. The control samples for the two periods have lower TSS values of 0.04mg/l and 0.03mg/l. All the TSS values for the harvested rainwater samples are within WHO recommendations of 600mg/l.

Hard water may not have serious health effects but they trigger consumer dissatisfaction. The harvested rainwater from the different roof materials in the study area (SC, AS, AL, TH and GZ) has mean Total Hardness values of 13.32mg/l, 23.10mg/l, 15.48mg/l, 12.03mg/l and 19.10mg/l respectively at the onset of rain. The peak period samples were characterised by a reduction in the mean Total Hardness values (9.23mg/l, 15,45mg/l, 10.00mg/l, 9.38mg/l and 12.21mg/l) for the different roof types SC, AS, AL, TH and GZ respectively. For each of the sample collection period, Asbestos roof (AS) has the highest mean Total Hardness values (Table 3 and 5, Figure 4 and 5). These mean total hardness values, together with those of

the control samples (7.2mg/l and 4.0mg/l) for the two rainfall periods are within the WHO (2017) guideline values for drinking water.

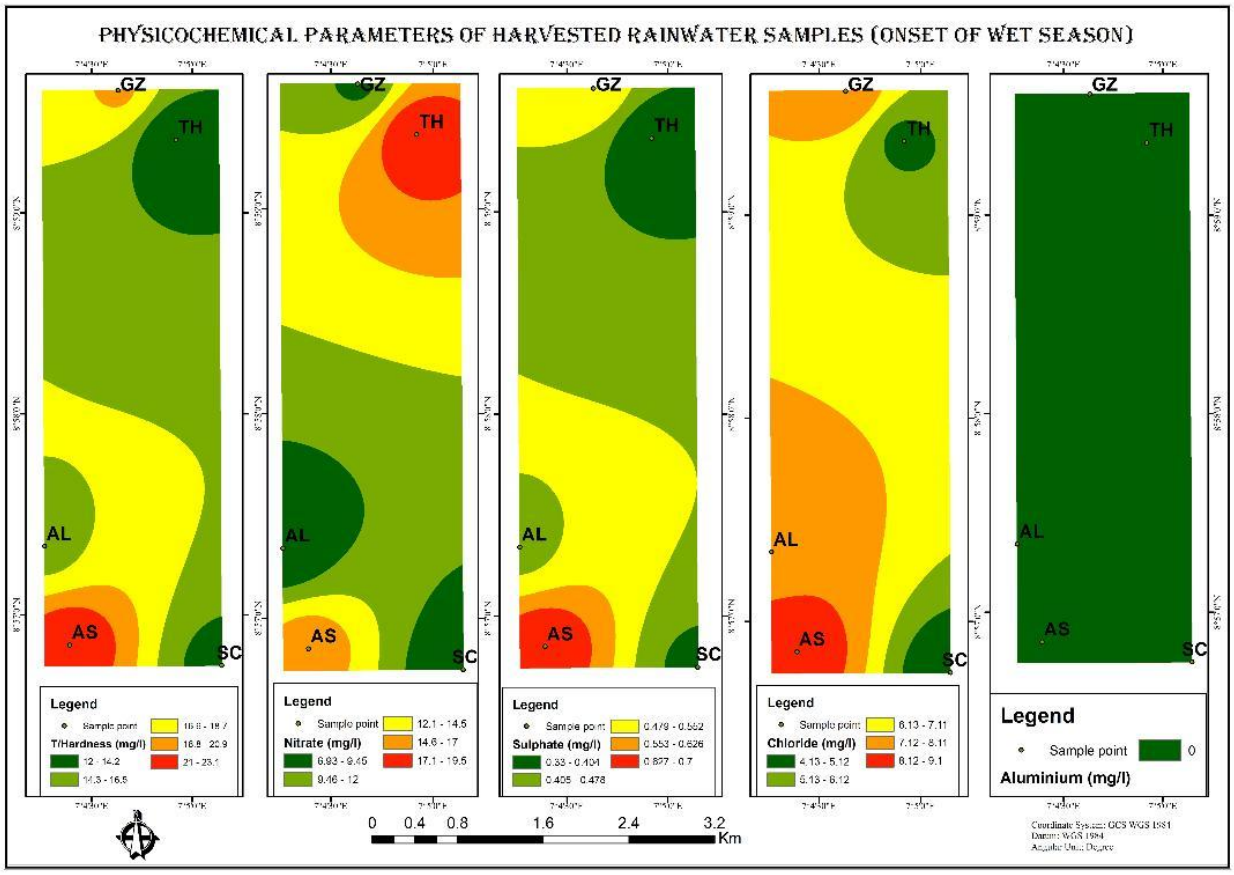


Figure 4: Spatial variation in Total Hardness, Nitrate, Sulphate and Chloride (Onset of wet season)
Source: Researcher's field work

The dissolution of emitted nitrogen oxides in rain is one of the major sources of nitrate in rainwater. The mean values of nitrate in the harvested rain water during the onset of rain ranged from 6.93mg/l (AL) to 19.55mg/l (TH). This is similar to the peak period samples mean nitrate value which ranges from 3.73mg/l (GZ) to 14.78mg/l (TH), except that their concentrations are reduced and the galvanized zinc roof has the lowest mean values (Table 3 and 5, Figure 4 and 5). The control samples for the onset rainfall period have nitrate concentration of 3.6mg/l but Nitrates was not detected in the peak period control sample. High levels of nitrate in drinking water can have serious adverse health effects. It affects the way the blood carries oxygen and can cause methaemoglobin. It can also cause weakness,

excessive heart rate, fatigue and dizziness (Ward *et al*., 2018).

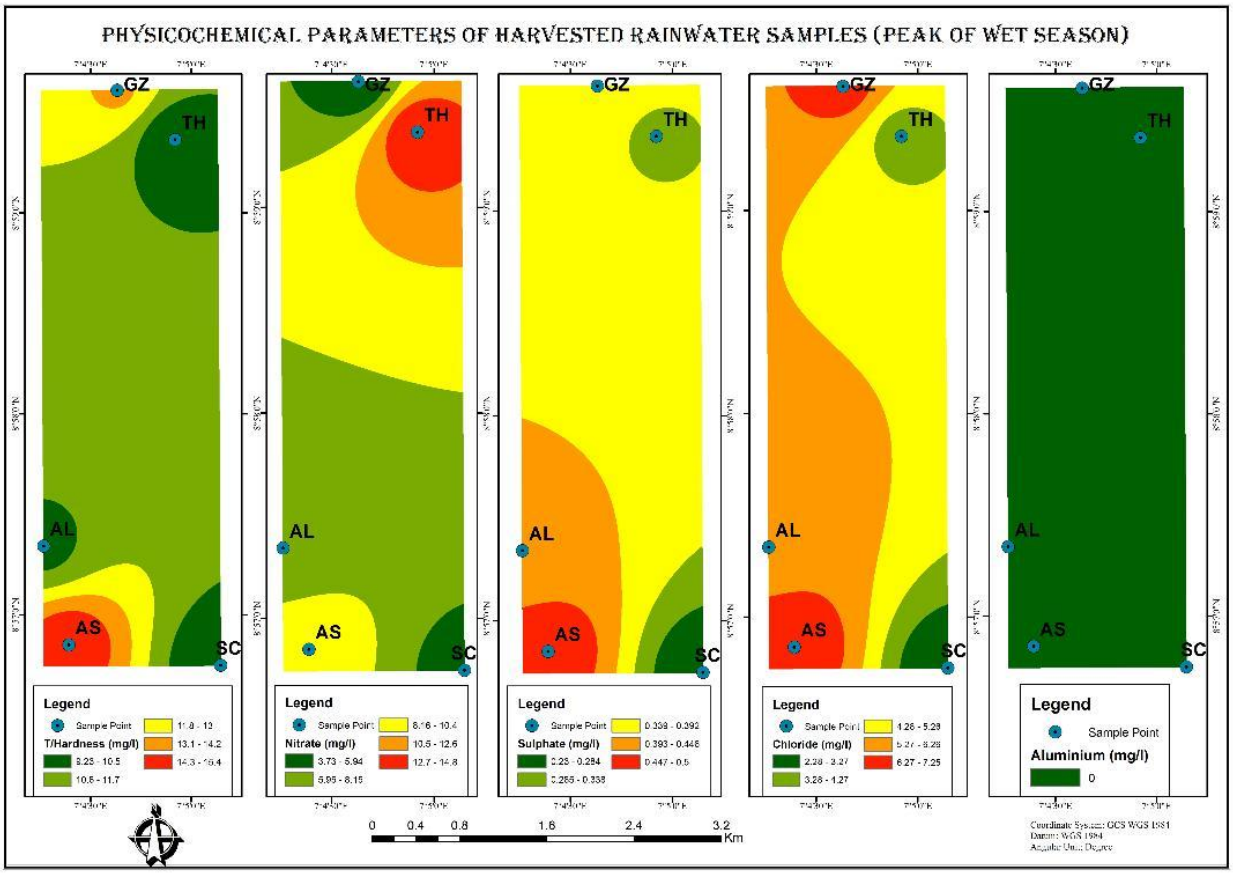


Figure 5: Spatial variation in Total Hardness, Nitrate, Sulphate and Chloride (Peak of wet season)
Source: Researcher's field work

Dissolved Sulphate in rainwater could be from a variety of sources which could be natural or anthropogenic. One of such sources is the oxidation and dissolution of oxides of sulphur emitted into the atmosphere, as well as from the washing off of sulphate containing materials from the roofs (USEPA, 2023). The mean sulphate concentration in the harvested rainwater samples ranged from is 0.33mg/l to 0.70mg/l at the onset of the wet season, while those of the peak period ranged from 0.23mg/l to 0.50mg/l. For each of the sample collection period, the rainwater samples from asbestos roof (AS) have the highest mean values of sulphate (Table 3 and 5, Figure 4 and 5).

0.2mg/l of sulphate was tested in the control sample at the onset of rain but it was not detected in the peak period control sample. All the rainwater samples have mean sulphate concentrations that are within the WHO (2017) standards for drinking water quality. Although sulphates in small amounts should not significantly affect the drinker, but at high levels, sulphate can give water a bitter or medicinal taste and can have laxative effects. Excessive sulphates intake can cause diarrhea, dehydration and gastrointestinal disorders (Backer, 2000; Makwe and Madu, 2021).

The mean concentration of chloride in the rainwater samples at the onset of rainfall is ranges from 4.13mg/l to 9.10mg/l across the different roof types. There is however a decrease in mean chloride concentration in the peak period samples across the different roof types and it ranged from 2.28mg/l to 7.25mg/l, with asbestos roof (AS) and stone coated roof (SC) having the highest and lowest mean chloride concentration respectively in both sampling periods. The control samples have chloride concentration of 1.80mg/l and 0.90mg/l for the onset and peak sampling periods respectively (Table 3 and 5, Figure 4 and 5).

The mean iron concentration in the rainwater samples ranged from 0.03mg/l (SC and TH roofs) to 0.20mg/l (GZ roof) at the onset of rain. There is however a decrease in the mean concentration of iron in the peak period rainwater samples ranging from 0.01mg/l (AL roof) to 0.12mg/l (GZ roof). Rainwater samples from galvanised zinc roof had the highest mean iron concentration for both sample collection periods, whereas there was no detection of iron in the water samples from SC and the control (CT) samples (Table 3 and 5, Figure 6 and 7). Having iron in drinking water is not directly hazardous to health because the body needs iron to function. However, high levels of iron in drinking water can affect the skin by increasing risks of suffering acne and other skin conditions. It also provides ideal breeding grounds for certain bacteria such as E. coli (Wright *et al*., 2014).

At the onset sampling period, Lead was detected in the rainwater samples from AS, AL, TH and GZ roofs, with mean concentration of 0.002mg/l, 0.001mg/l, 0.001mg/l and 0.001mg/l respectively. There was no detection of lead in the peak period rainwater samples as well as the control samples (Table 3 and 5, Figure 6 and 7) Lead is a powerful neurotoxin and exposure to lead can lead to brain damage,

injuring of soft tissues and organs as well as interference with blood formation in both children and adults (WHO, 2019; USEPA, 2023).

At the onset of the wet season, zinc was detected only in the rainwater samples from aluminium (AL) and galvanized zinc (GZ) roofs with mean concentration of 0.008mg/l and 0.018mg/l respectively. There was no detection of zinc in the peak period samples except for those from the galvanised zinc roof type, with mean concentration of 0.015mg/l. There was also no detection of zinc in the control samples from both sampling period (Table 3 and 5, Figure 6 and 7). Elevated concentration of zinc in drinking water has gastrointestinal, immunological, cardiovascular as well as neurological effects on children and adults (Sankhla *et al*., 2019)

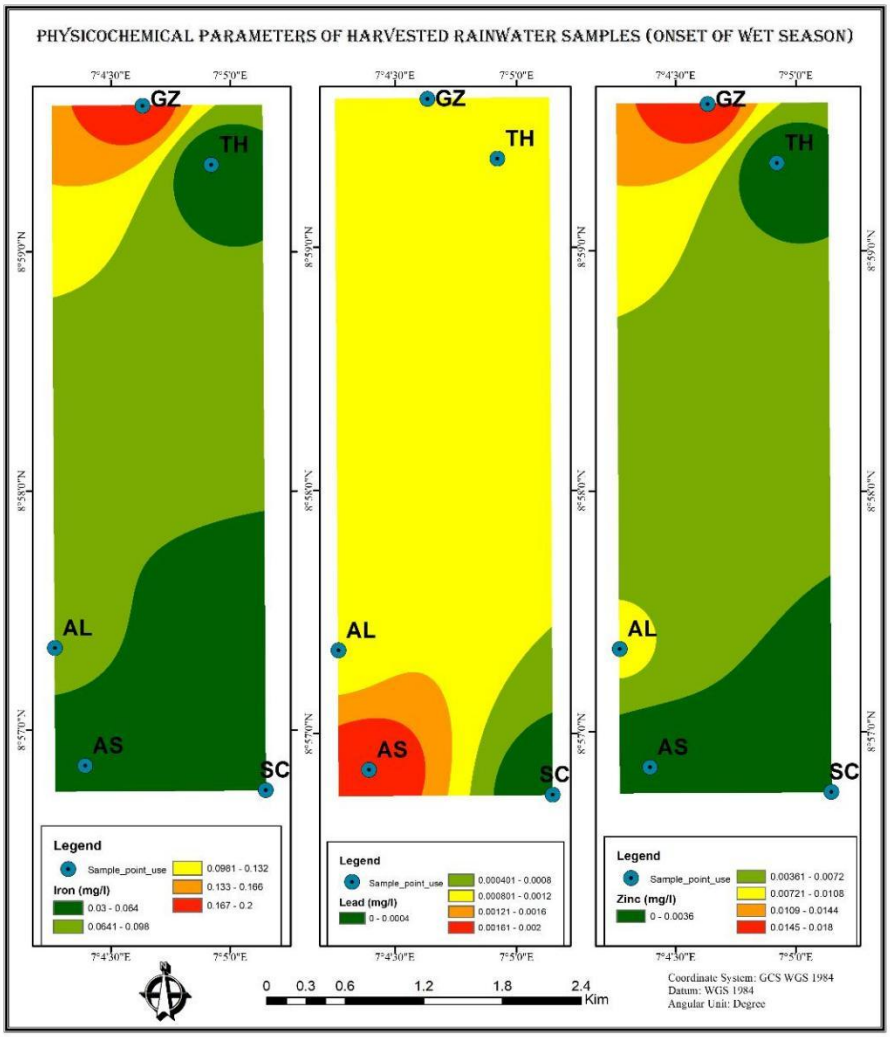


Figure 6: Spatial variation in Iron, Lead and Zinc (Onset of wet season)
Source: Researcher's field work

Aluminium was not detected in any of the harvested rainwater samples across the different roof types in the two sampling periods (Table 3 and 5, Figure 6 and 7).

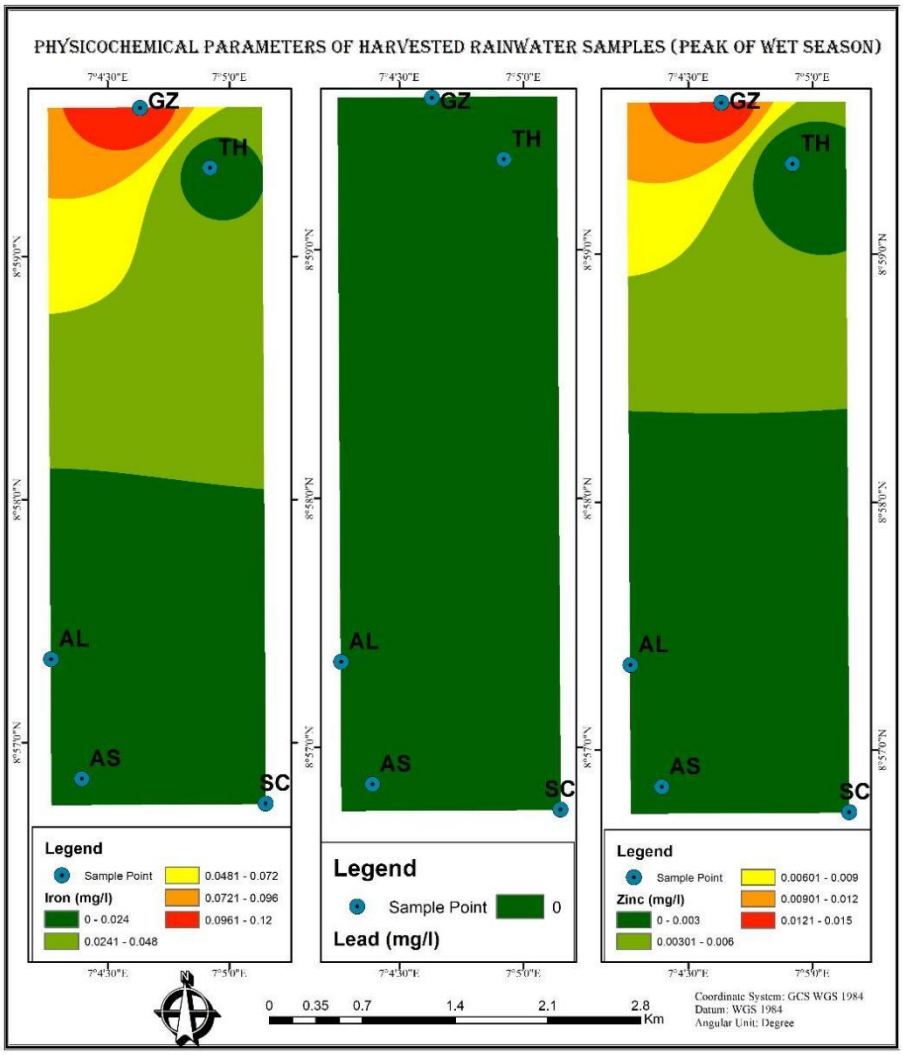


Figure 7: Spatial variation in Iron, Lead and Zinc (Peak of wet season)
Source: Researcher's field work

4.2 Variation in Microbiological Parameters of Rainwater Samples

Generally, the concentration of the tested biological parameters in the rainwater samples were higher at the onset of the wet season: total coliform (1.2cfu/ml to 18.2cfu/ml), *E. coli* (0.2 cfu/ml to 4.8 cfu/ml), Enterobacter (0.1 cfu/ml to 3.4

cfu/ml) and Klebsiella (0.1 cfu/ml to 3.6 cfu/ml). For each of these parameters, samples from thatched roof (TH) had the highest concentration, while those from aluminum roof (AL) had the lowest concentration. There is however, a decline in the concentration of same parameters in the peak period samples as follows: total coliform (0.6cfu/ml to 7.4cfu/ml), *E. coli* (0.1cfu/ml to 2.5 cfu/ml), Enterobacter and Klebsiella had the highest mean concentration in the TH roof rainwater samples (1.1cfu/ml and 0.9cfu/ml respectively) but they were not detected in the AL roof rainwater samples. The control samples were also devoid of these parameters for both sampling periods (Tables 4 and 6, Figures 8 and 9). The decline in the concentration of the tested biological parameters in the peak period samples is most likely due to roof wash by subsequent rainfalls before the collection of the samples. The detected biological parameters across the different roof types in the two sampling periods are higher than the 0.0cfu/ml WHO (2017) standard recommendations.

E. coli, Enterobacter and Klebsiella are commonly found in the lower intestine of warm-blooded organisms and are therefore of feacal origin. However, Enterobacter and Klebsiella are also ubiquitous in nature. Faecal material on the roof surface has been cited as one of the major sources of contamination in Roof Harvested Rainwater as faeces of birds, insects, mammals, and reptiles that have access to the roof can potentially contain a wide array of pathogens (Hamilton *et al*., 2019; Bae *et al*., 2019; Zdeb *et al*., 2020). The results from this research are in agreement with this notion. During rain events, debris on the roof surface, including animal droppings, can be washed by the roof runoff. The contamination of drinking water by these pathogens can cause any of a variety of conditions, including severe stomach cramps, bloody diarrhea and vomiting, eye and skin infections, meningitis, bacteremia (bacterial blood infection), pneumonia, and urinary tract infections.

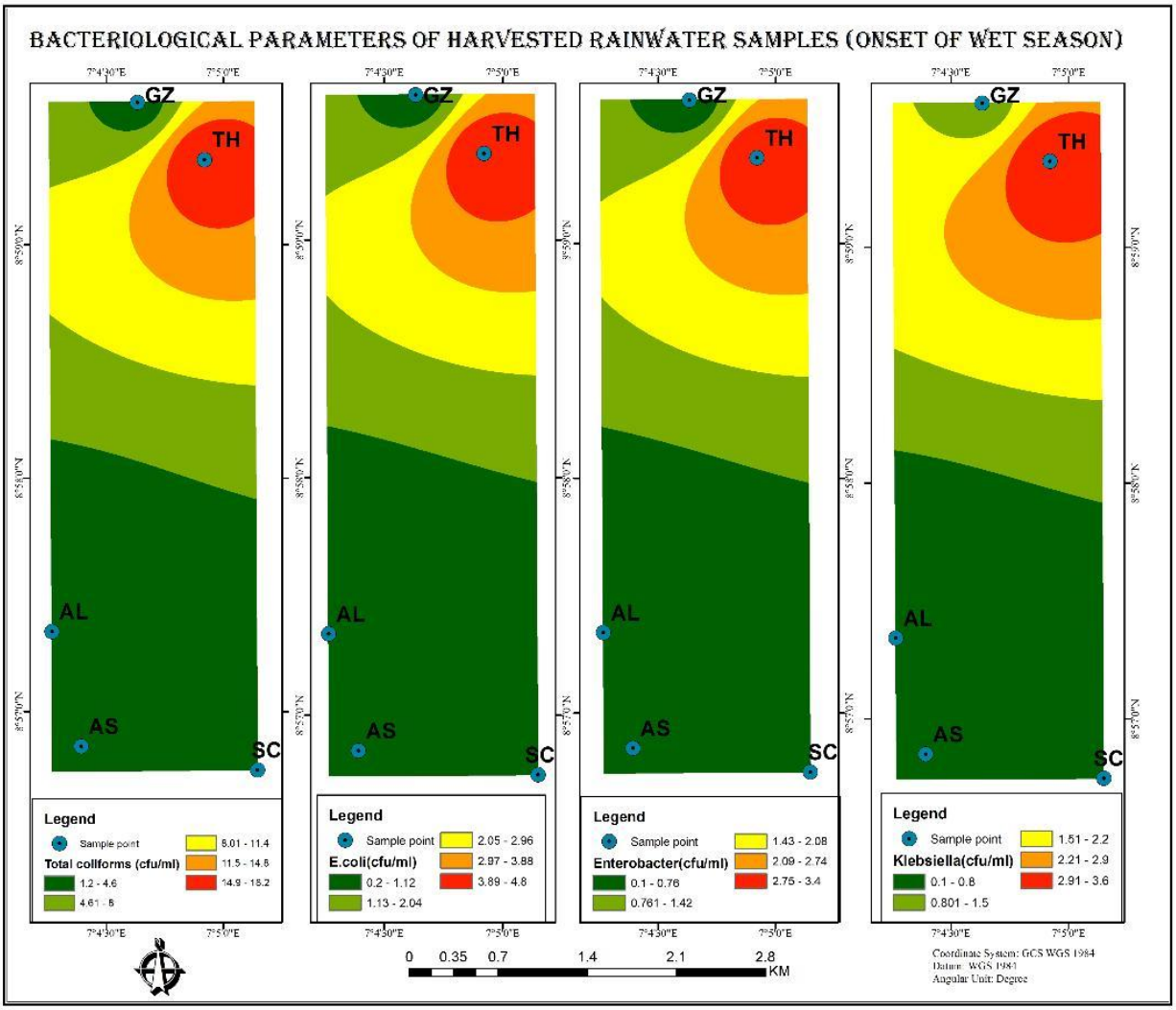


Figure 8: Spatial variation in Total coliform, E. coli, Enterobacter and Klebsiella (Onset of wet season)
Source: Researcher's field work

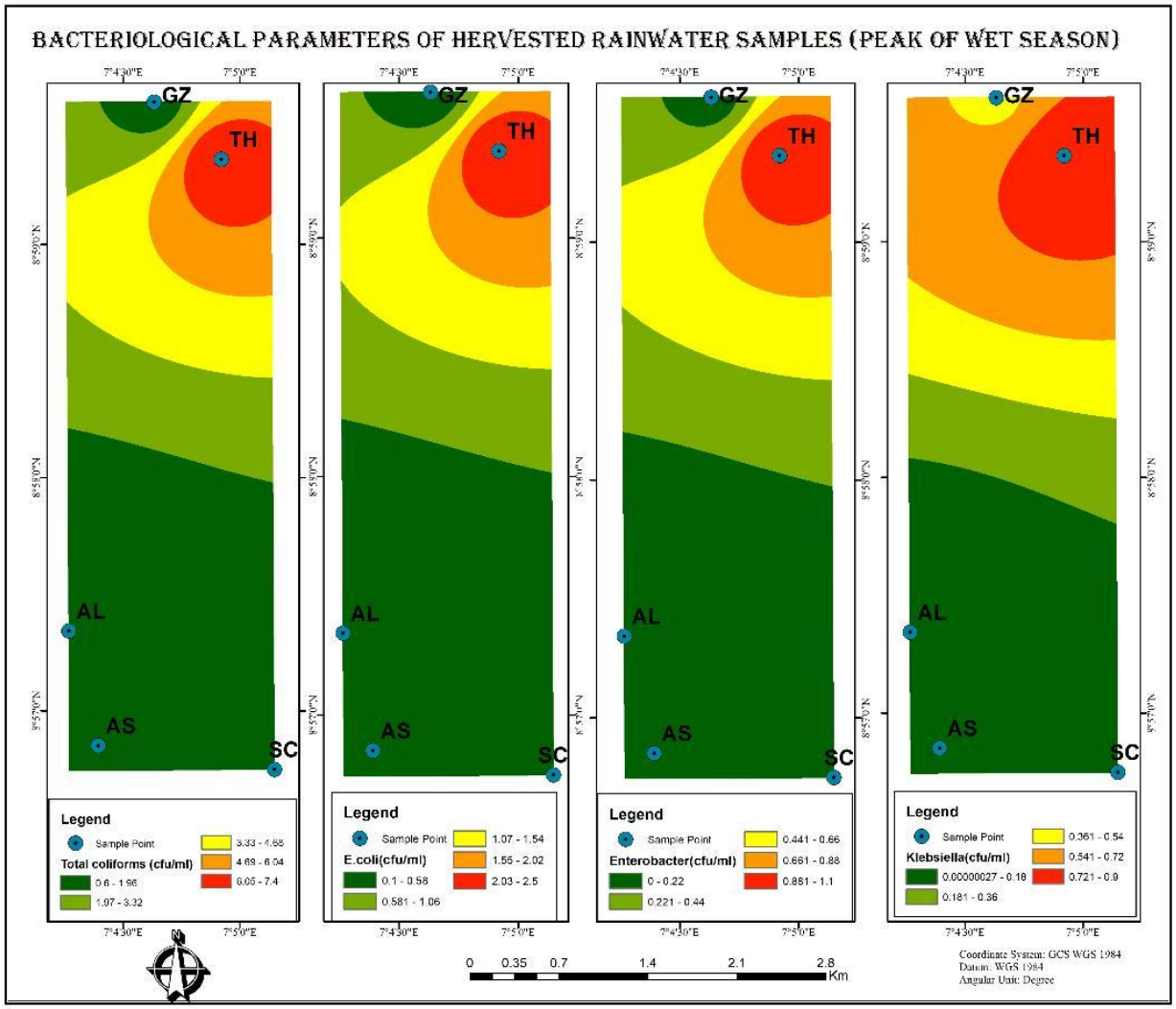


Figure 9: Spatial variation in Total coliform, E. coli, Enterobacter and Klebsiella (Peak of wet season)
Source: Researcher's field work

For both the onset and peak of the wet season, the ANOVA results indicates that there is no significant variation in the concentration of the tested parameters across the different roof types (SC, AS, AL, TH, GZ). This is evidenced by the high P-values, which are well above the common significance level of 0.05 as seen in Table 7.

Table 7: Analysis of Variance

ANOVA for Onst of Wet Season						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	3293.93324	4	823.4833088	0.110391348	0.978556595	2.485884938
Within Groups	596773.802	80	7459.672529			
Total	600067.736	84				
ANOVA for Peak of Wet Season						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	252.4974	4	63.12434005	0.545908476	0.702566002	2.502656463
Within Groups	8094.221	70	115.6317273			
Total	8346.718	74				

5.0 Conclusion and Recommendations

This study analysed and compared the quality of roof harvested rainwater from five different rooftops in Gwagwalada, Federal Capital Territory. The physical, chemical and bacteriological parameters of the rainwater samples collected from stone coated, asbestos, aluminium, thatch and galvanized zinc rooftops catchments generally showed slightly elevated concentrations for samples collected at the onset of rain (April), while the peak period (July) samples showed less concentration for the analysed parameters. From the laboratory analysis and the IDW spatial interpolation, the physical and chemical parameters showed no much detectable variation pattern of water quality amongst the five selected roof types. However, samples from asbestos and thatch roofs had more parameters that showed highest contamination level (EC, Turbidity, TDS, TSS, Nitrate, Sulphate and Chloride). For the bacteriological parameters (Total coliform, *E.coli, Enterobacter and Klebsiella*), the thatch roof (TH) water samples had the highest concentration while the aluminium roof (AL) water samples had the least concentration in both sampling periods (onset and peak of rain), with *Enterobacter* and *Klebsiella* being absent in the peak period water samples from AL roof. Most of the analysed physical and chemical parameters were within the WHO permissible limits for drinking water but the bacteriological analysis showed evidence of contamination. For both the onset and peak of the wet season, the ANOVA results indicates that there is no significant variation

in the concentration of the tested parameters across the different roof types (SC, AS, AL, TH, GZ).

The presence of microbiological pollutants in the water makes it unfit and unhealthy for consumption due to their capacity to multiply. To ensure that the rainwater satisfies health requirement for consumption, all harvested rainwater should be adequately treated before consumption. It is also important to clean the roof gutters from time to time and ensure that water does not stagnate inside the gutter pipes. In addition, trees and other overhanging materials which can provide access to the roof by animals and birds should be cleared form the roof. The result of this study corroborates those of Ezemonye *et al* (2016), Thomas and Kouame (2019) and Tiwari *et al* (2021)

Acknowledgement

The authors wish to acknowledge the management of Zabson Laboratories Abuja, Nigeria, for their contribution in the analysis of the rainwater samples.

Declaration of Competing Interest

The authors report there are no competing interests to declare

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