INFLUENCE OF CATCHMENT SURFACE AND HARVESTING TIME ON QUALITY OF RAINWATER IN A PERI-URBAN SETTLEMENT

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Abstract

The study examines the effect that catchment surface and harvesting period had on quality of harvested rainwater. The study was carried out in Kotopo area of Abeokuta metropolis, Nigeria. There is the need to investigate the safety of harvested rainwater in that area because the inhabitants of the area depend on rainwater for drinking, cooking, washing and other domestic purposes. A 2 factor, 4 levels General factorial experimental design (GFD) was selected for the study using Design expert® 8.0 software. The first factor (Catchment surface) considered included Corrugated iron sheet, Aluminum sheet, Aluminum-zinc alloy sheet, and Control (open air) while the second factor (Period of collection) included the month of March, April, May and June. PH, electrical conductivity (EC), and total dissolved solids (TDS) was determined using (PH/EC/TDS) meter; while iron, zinc and Aluminum were determined using Atomic Absorption Spectrophotometer (AAS); chloride was also determined using argentometric method. Total coliform count (TCC) and total bacteria count (TBC) were also determined using multiple tube tests and plate count method respectively. The data obtained from the study was analyzed using design expert® 8.0 software for analysis of variance (ANOVA). The results from the study were compared with Standard Organization of Nigeria (SON), World Health Organization (WHO), European Union and Bureau of Indian stipulated standards of rainwater quality for domestic use. The average values of the analysis were: (6.87 pH, Chloride 29.00mg/l, Electrical conductivity 32.94µs/cm, total iron 0.016mg/l, total dissolve solids 3.33 mg/l, Zinc 0.19 mg/l, total coli form count 4593.75, and Aluminum 0.023mg/l). The total bacteria count was found to be Zero throughout the period of collection and on the entire catchment surface. This shows that the rainwater is free of bacterial throughout the period of collection and the rain is not acidic since the average pH of the sample is found to be close to neutral 6.87. With the exception of coli form count, which has no guideline from World Health Organization (WHO), Bureau of Indian Standard (BIS), the European Union (EU) standard, but only in Standard Organization of Nigeria (SON), the study showed that rainwater meant for domestic purposes is safe for harvesting throughout the period of collection using the stipulated catchment surfaces. Harvested rainwater is therefore, recommended for the domestic use of inhabitants of Kotopo area of Abeokuta metropolis to reduce indiscriminate drilling of boreholes in the metropolis which could cause earthquake and over abstraction of ground water with attendant negative consequences.

Key Words: Rainwater; Water quality; Catchment surface; Collection period

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Introduction

Water is an essential natural resources on the earth needed for life sustenance, and its demand is growing in most cities of Nigeria. It has long been suspected of being the source of much human illnesses (Clair *et al*., 2002). According to UNICEF estimates, globally no fewer than 1,400 under-five children die every day from diarrhea diseases linked to lack of safe water, adequate sanitation and hygiene (Godwin, H., 2014). Multi-indicator cluster survey published in 2013 by the National Bureau of Statistics of Nigeria showed that nearly 70 million Nigerians lacked access to safe water in 2011 thereby placing Nigeria as the third country globally with most people without access to safe water (Godwin, H., 2014). Water plays an important role in the world economy, it functions as a solvent of many chemical processes without which life will remain a mirage. Access to safe drinking water has improved steadily and substantially over the last decades in most part of the world (Fang and Ye., 2012; Lomborg and John, 2001).

However, it had been noted that some observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability (Fang and Ye., 2012) (Kulshreshtha, 1998; Balgovind, 2009). Report, according to Fang and Ye, (2012), suggests that by 2030 in some developing regions of the world, water demand will exceed supply by 50% (Fang and Ye., 2012). Lack of access to safe water is a threat to developing economies such as Nigeria, which loses around ₦455 billion – 1.3 per cent of its Gross Domestic Product (GDP) each year due to poor water, sanitation and hygiene and its effect (Alex, 2014).

In many countries, rainwater continues to be an important source of water in isolated home stead; farm collection and storage for agricultural uses, which had been widely practiced for thousands of years. In the last two decades, interest in rainwater has grown; its utilization is now an option along with more traditional water supply technologies particularly in rural areas (Gould and Nissen, 1999). It is of particular importance and relevance for arid and semi-arid remote and scattered human settlement. In Nigeria, there are no concerted efforts to adopt the use of rainwater harvesting technologies in order to augment supply. Being a tropical country, the nation is blessed with at least five months of rainfall in the south and four months in the northern part of the country.

The public taps are most of the time dry, making access to clean, and portable water very low. Rainwater harvesting is one of the important sources of water for domestic uses identified in the Nigerian National Water Policy (2004), but its implementation by government is non-existent. Nigeria government had the target of increasing water coverage by 75 per cent by 2015, records show that coverage of water have been on a steady decline from 37 per cent in 1990 to 31 percent in 2011(Alex, 2014). Millions of cubic meters of water that could be used to augment supply are allowed to runoff into streams, rivers etc., during the rainy season thereby causing floods and creating erosion hazards along its path. A percentage of this water can be harvested for domestic uses especially in areas with basement complex geological formations which has groundwater yield of < 2 l/min. Literatures reports that these crystalline igneous/metamorphic rock formation underlays over 60 % of the country's landscape (Eroarome, 2009). Communities in these areas are always perplexed by acute water scarcity for domestic purposes.

Rainwater harvesting has been practiced for centuries in Nigeria, but in many homes observed by the study its application is at a very low scale and hardly could one see a cistern for collection of rainwater that has a capacity beyond 1000 liters. It is common to see women and children collecting rainwater with buckets. In proposing a rainwater harvesting technology, to reduce indiscriminate drilling of boreholes in the metropolis, which could cause earthquake, and over abstraction of ground water with attendant negative consequences, the quality of the harvested water is of grave importance, this is largely determined by the type of materials used as a catchment surface (Roof material). Several materials are used for roofing in South-west Nigeria which includes: Asbestos, Galvanized iron, Aluminum, concrete, Aluminum-Zinc alloy. These materials no doubt have some health implications as it must have certain impact on the quality of rainwater harvested from them as catchment surface (Carolina, *et al*., 2010). Asbestos for example has been confirmed to be carcinogenic hence the discontinuation of its use as a material for water pipes (Barrett *et al*., 1989; O'Reilly *et al*., 2007; Shinya, 2009; Kirt, 2011; ATSDR, 2014; WHO, 2014). Hence, the paper is to examine the effect that catchment surface and harvesting time (period of collection) has on the quality parameters of harvested rainwater using Kotopo area of Abeokuta as a case study.

Materials and Methods

The study was carried out in Abeokuta, Ogun State, Nigeria; a number of roofing materials available in the south-western part of Nigeria was purposefully selected, this is because the catchment surface is the most critical component of a rain water harvesting system. A 2 factor, 4 levels General factorial experimental design (GFD) was selected for the study using Design expert® 8.0 software. The first factor (Catchment surface) considered included corrugated iron sheet, Aluminum sheet, Aluminum-zinc alloy sheet, and Control (open air) while the second factor (Period of collection) included the month of March, April, May and June of year 2011; these months were selected because they are the most critical months of serious water scarcity and the onset of the wet season.

Water samples were collected using standard sample bottles (100ml) for laboratory analysis while sterile containers were used for microbiological examination, sample collection was done after the roof had been flushed by the rain for about 10 minutes; a total of 16 experiments and 144 chemical analyses were carried out to determine pH, electrical conductivity (EC), total dissolved solids (TDS) using (pH/EC/TDS) meter; while iron, zinc and Aluminum were determined using Atomic Absorption Spectrophotometer (AAS); chloride was also determined using argentometric method. Total coliform count (TCC) and Total Bacteria count (TBC) were also determined using multiple tube tests and plate count method respectively. The data obtained from the study was analyzed using design expert® 8.0 software for analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The results of the Laboratory analysis are presented in Table 1.

Table 1: Result of laboratory analysis

FACTOR 1	FACTOR 2	1	2	3	4	5	6	7	8	9
Catchment surface	**Period of collection**	**pH**	**Chloride (mg/l)**	**E. C. (μs/cm)**	**T. D. S. (mg/l)**	**T. Iron (mg/l)**	**Aluminum (mg/l)**	**Zinc (mg/l)**	**B.C.**	**Coliform Count**
AL SHEET	MAR	6.63	6.00	31	16	0.0198	0.03	0.0101	NIL	4.5
G I SHEET	MAR	6.60	13.00	45	22	0.0133	0.01	1.2444	NIL	4
ALU-ZINC	MAR	6.45	10.00	33	16	0.016	0.04	0.1137	NIL	NIL
CONTROL	MAR	7.50	29.00	227	115	0.0175	0	0.0047	NIL	1.1
AL SHEET	APRIL	6.51	90.08	9	4	0.027	0.01	0.0119	NIL	8.8
G I SHEET	APRIL	6.68	90.53	12	6	0.019	0.02	0.8879	NIL	2.9
ALU-ZINC	APRIL	6.51	108.28	9	4	0.0127	0.02	0.1785	NIL	1.24
CONTROL	APRIL	6.86	42.6	39	19	0.0268	0.02	0.0275	NIL	2.96
AL SHEET	MAY	7.1	7	2	1	0.085	0.02	0.0104	NIL	1.1
G I SHEET	MAY	7.25	5	7	3	0.0151	0.02	0.2508	NIL	2.8
ALU-ZINC	MAY	7.03	6	3	1	0.0154	0.01	0.016	NIL	3.3
CONTROL	MAY	7.78	8	36	18	0.0147	0.03	-0.0158	NIL	600
AL SHEET	JUNE	6.7	7	11	5	0.0195	0.01	0.011	NIL	2800
G I SHEET	JUNE	6.66	6	10	5	0.0118	0.03	0.2044	NIL	1700
ALU-ZINC	JUNE	6.3	4	8	4	0.0122	0.04	0.177	NIL	1100
CONTROL	JUNE	7.3	3	45	22	0.012	0.04	0.0015	NIL	400

Source

The analyses of variance (ANOVA) for the parameters determined are presented in Tables 3- 10. The response of each parameter to catchment surfaces and period of collection are presented in figures 1-8 and the trend of each parameter in water samples from catchment surfaces are presented in figures 9-16.

The pH values of the sample on the entire catchment surface shows that there are no significance over the period of collection and the values ranges from 6.45-7.78 and a mean of 6.9 which is within the range of Standard Organization of Nigeria(SON), World Health Organization(WHO) and Bureau of Indian Standard (BIS) guidelines as shown in Table 2.

The electrical conductivity of the sample on the entire catchment surface shows that there are no significance over the period of collection and the values ranges from 2-227µs/cm and has a mean of 37.75µs/cm which is within the range of Standard Organization of Nigeria (SON), World Health Organization (WHO) and the European Union standard as shown in Table 2. The Zinc values of the sample on the entire catchment surface, and found to be very minimal in control, which shows that there is significance over the period of collection and the values ranges from -0.0067 to 1.2444 mg/l and a mean of 0.61 mg/l which is within the range of Standard Organization of Nigeria (SON), World Health Organization (WHO) and Bureau of Indian Standard (BIS) guide lines as shown in Table 2.

The Total Iron (T.I.) values of the sample on the entire catchment surface, and found to be very minimal in control, which shows that there is no significance over the period of collection and the values ranges from 0.0085-0.027 mg/l and a mean of 0.31 mg/l which is within the range of Standard Organization of Nigeria(SON), World Health Organization (WHO) and Bureau of Indian Standard (BIS) and the European Union (EU) guide lines as shown in Table 2. The Total Dissolve Solids (T.D.S.) values of the sample on the entire catchment surface, which shows that there is no significance over the period of collection and the values ranges from 1-115 mg/l and a mean of 2.07 mg/l which is within the range of Standard Organization of Nigeria (SON), Bureau of Indian Standard (BIS) and the European Union (EU) guide lines as shown in Table 2.

The Total Coli (T.C.) form count values of the sample on the entire catchment surface, which shows that there is no significance over the period of collection and the values ranges from 281.56-10968.44 and a mean of 5625. There are no guidelines concerning coli form by World Health Organization (WHO), Bureau of Indian Standard (BIS) and the European Union (EU) guidelines as shown in Table 2. It is however still within the range as stipulated by Standard Organization of Nigeria (SON).

The Chloride values of the sample on the entire catchment surface shows that there are no significance over the period of collection and the values ranges from 5-90mg/l and a mean of 37.5mg/l which is within the range of Standard Organization of Nigeria (SON), World Health Organization (WHO) and Bureau of Indian Standard (BIS) and the European Union guide lines as shown in Table 2. The Total Bacterial count was found to be nil in all the samples with respect to the period of collection and the catchment surfaces which also conform to the guide line given in Table 2, by the European Union, that 0 bacteria should be found in 100ml.This also shows that the rainwater samples are free of bacterial.

Table 2: Water Quality standard of Rain water for domestic use.

Parameters	Standard Organization of Nigeria	World Health Organization	European Union	Bureau of Indian Standard
PH	6.5-8.5	6.5-8.5	Not Mentioned	6.5-8.5
EC	1000µs/cm	250µs/cm	250µs/cm	Not mentioned
TDS	500mg/l	No guideline	500mg/l	200mg/l
Al	0.2 mg/l	0.2mg/l	o.2mg/l	No guideline
Fe	0.3 mg/l	0.3mg/l	0.2mg/l	1.0mg/l
Zn	3 mg/l	3mg/l	Not mentioned	15mg/l
Cl	250 mg/l	250mg/l	250mg/l	100mg/l
TBC	0 cfu/100ml	Not mentioned	0 cfu/100ml	No guideline
TCC	10 cfu/ml	No guideline	No guideline	No guideline

Source: SON (Nigerian Standard for Drinking -Water Quality (NSDQW), 2007); WHO (Guidelines for Drinking-water Quality, 3rd Edition, 2008); EU (European Union (Drinking Water) Regulations 2014, BIS (Indian Standard for Drinking water- Specification IS 10500:1991).

Table 3: Analysis Of Variance (ANOVA) for pH

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	2.63	15	11	0.18	
Total	2.63	15	11		

Source

Table 4: Analysis Of Variance (ANOVA) for Electrical conductivity

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	43740.94	15	2916.06	11	
Total	43740.94	15		11	

Source

Table 5: Analysis Of Variance (ANOVA) for Coli form count

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	8.321E+008	15			
Total	8.321E+008	15		5.548E+007	

Source

Table 6: Analysis Of Variance (ANOVA) for Total Dissolve Solids

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	11277.44	15	751.83		
Total	11277.44	15			

Source

Table 7: Analysis Of Variance (ANOVA) for Total Iron

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	3.978E-004	15	2.652E-005		
Total	3.978E-004	15			

Source

Table 8: Analysis Of Variance (ANOVA) for Zinc ANOVA

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	1.13	3	0.38	5.76	Prob>f
A-catchment	1.13	3	0.38	5.76	0.0112
Residual	0.79	12	0.066		0.0112
Total	1.92	15			

Source

Table 9: Analysis Of Variance (ANOVA) for Chloride

Source	Sum Of Square	Degree Of Freedom	Mean square	F-Value	P-Value
Model	16728.18	3	5576.06	24.80	< 0.0001
B-period of collection	16728.18	3	5576.06	24.80	< 0.01(significant)
Residual	2698.00	12	224.83		
Total	19426.18	15			

Source

Table 10: Analysis Of Variance (ANOVA) for Aluminum

Source	Sum Of Square	Degree Of Freedom	Mean Square	F- Value	P-Value
Model	0.000	0			Prob>f
Residual	2.244E-003	15	1.496E-004		
Total	2.244E-003	15			

Source

Table 11: Summary of Statistics for Rainwater Quality Parameters

Parameters	**Range**	**Mean**	**Standard deviation**	**Predicted r^2**
PH	6.64-7.09	6.87	0.42	-0.1378
Electrical Conductivity	4.16-61.71	32.94	54.00	-0.1378
Coli form count	624.85-8562.65	4593.75	7448.26	-0.1378
Total Iron	0.014-0.019	0.016	5.150E-003	-0.1378
Zinc	-0.0067-1.2444	0.19	0.28	0.2715(Significant)
Chloride	19.05-35.39	27.22	14.99	0.7531(Significant)
Total Dissolve Solids	1.70-30.92	16.31	27.42	-0.1378
Aluminum	0.015-0.028	0.022	0.012	-0.1378

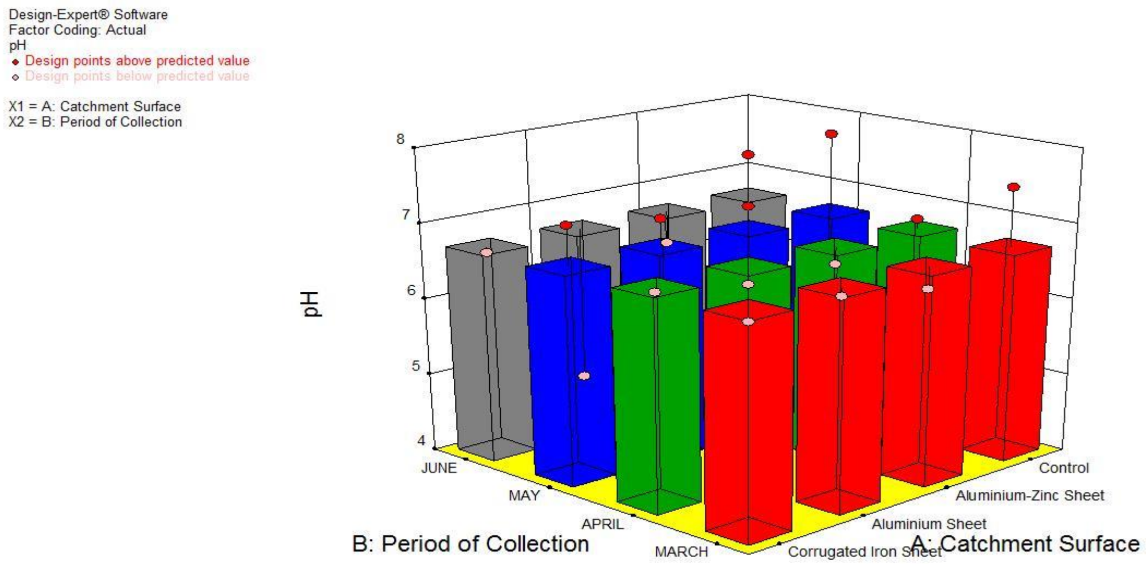

Figure 1: pH response to Catchment surface and period of collection

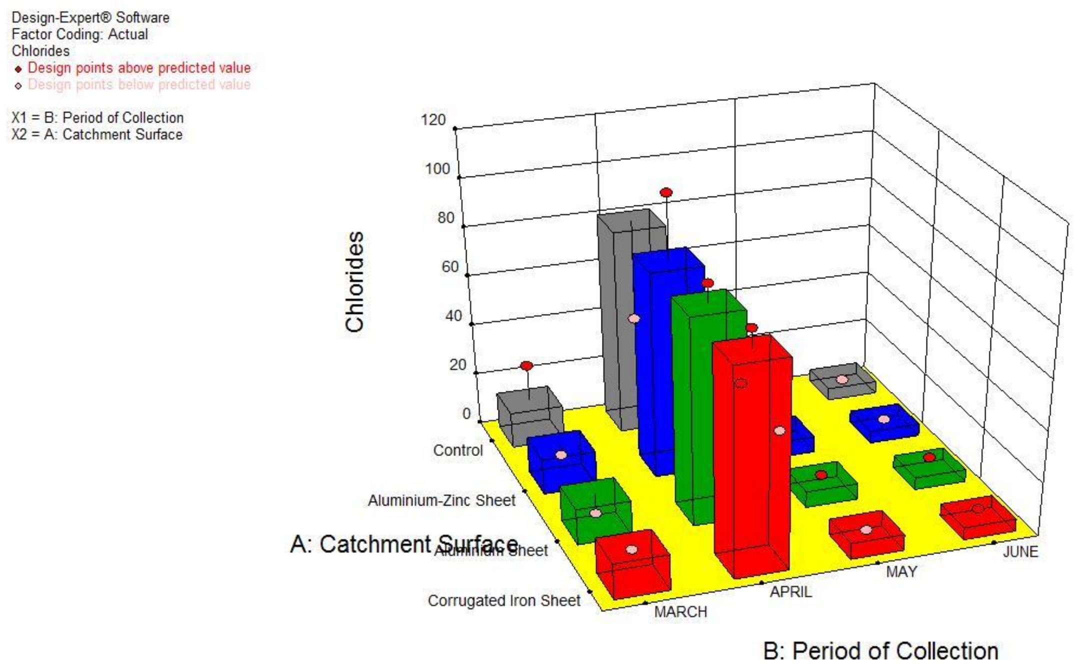

Figure 2: Chloride response to Catchment surface and period of collection

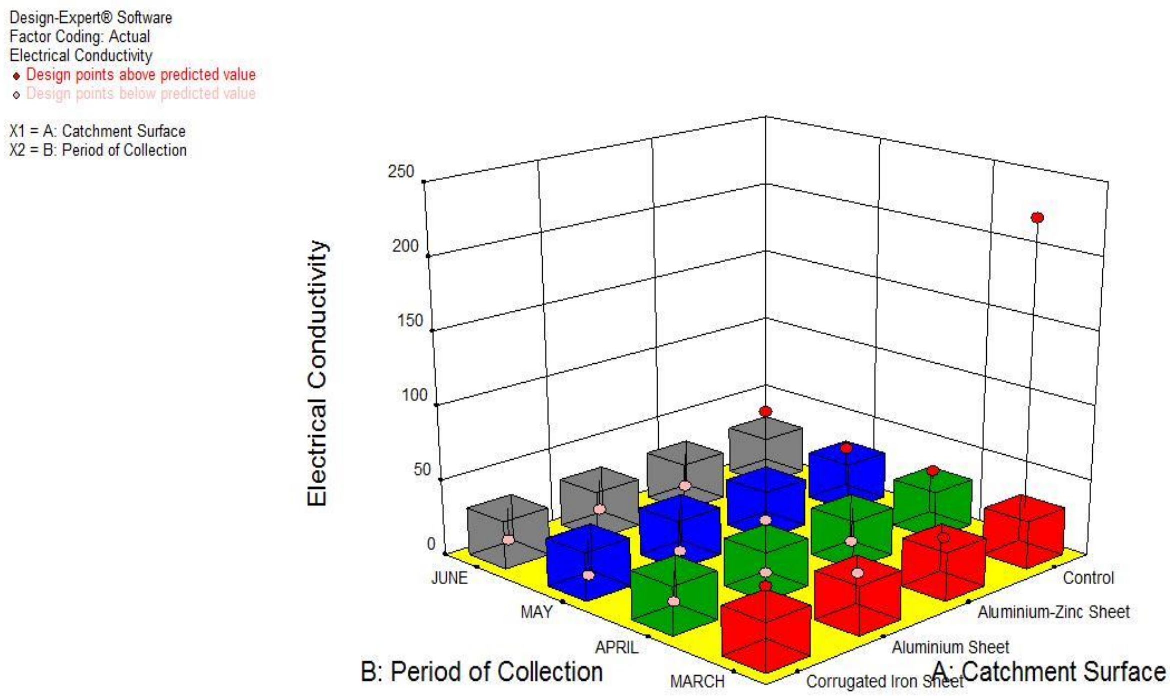

Figure 3: Electrical conductivity response to catchment surface and period of collection

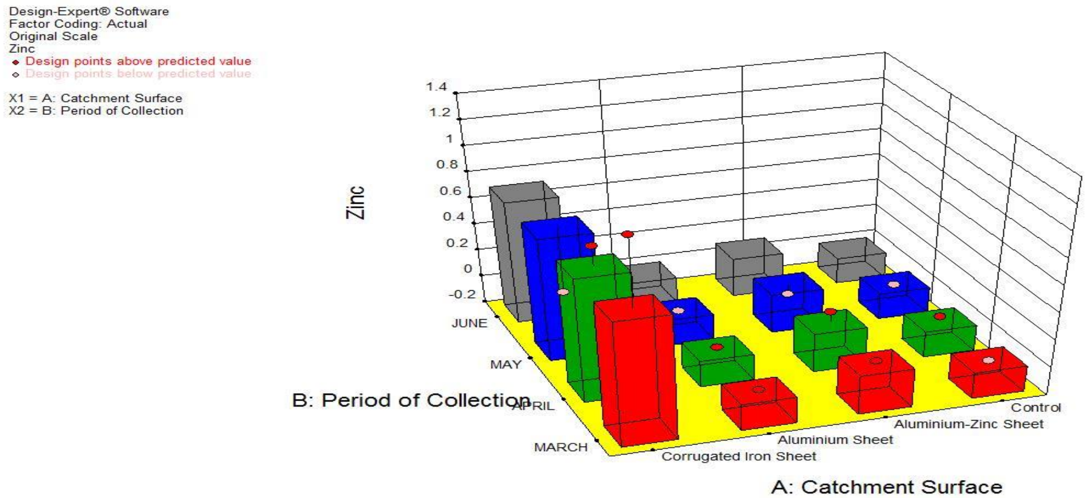

Figure 4: Zinc response to catchment surface and period of collection

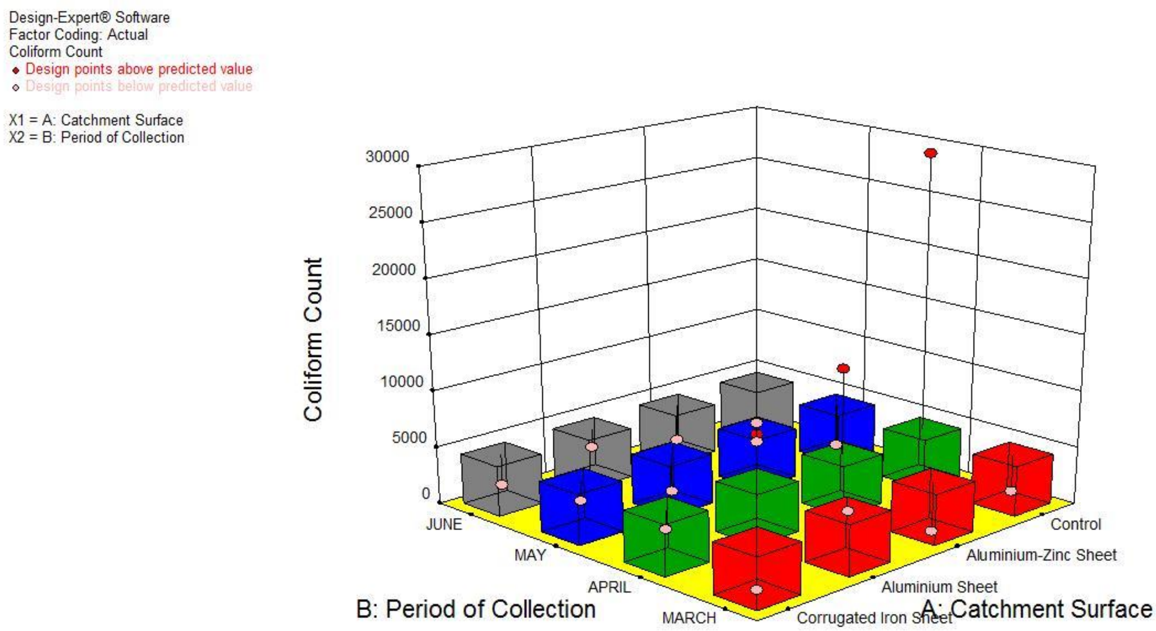

Figure 5: Coli form count response to catchment surface and period of collection

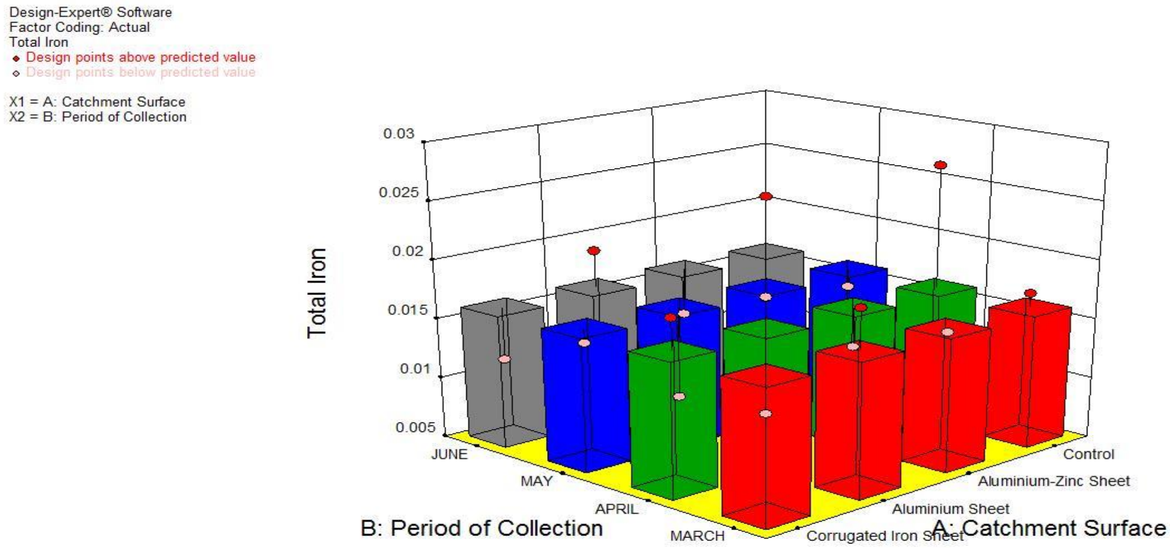

Figure 6: Total Iron response to catchment surface and period of collection.

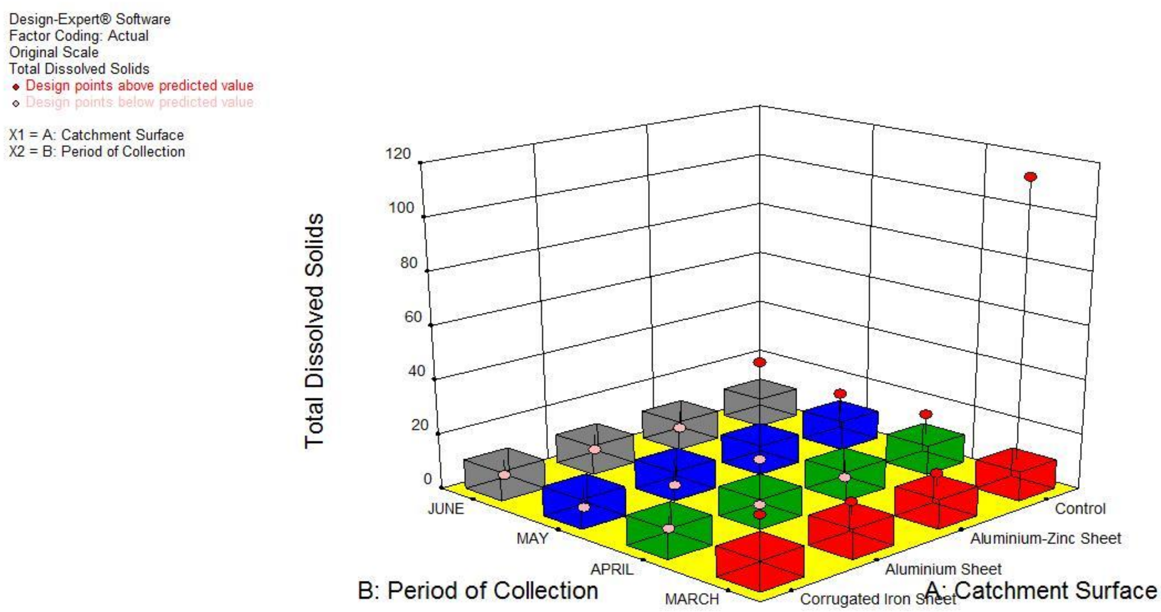

Figure 7: Total Dissolve Solids response to catchment surface and period of collection

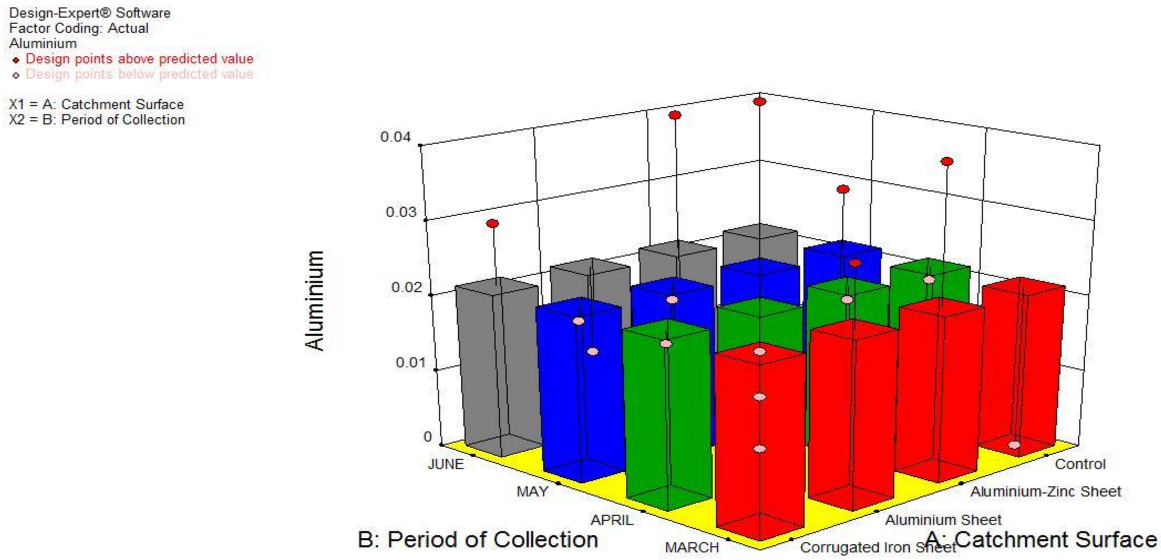

Figure 8: Aluminum response to catchment surface and period of collection

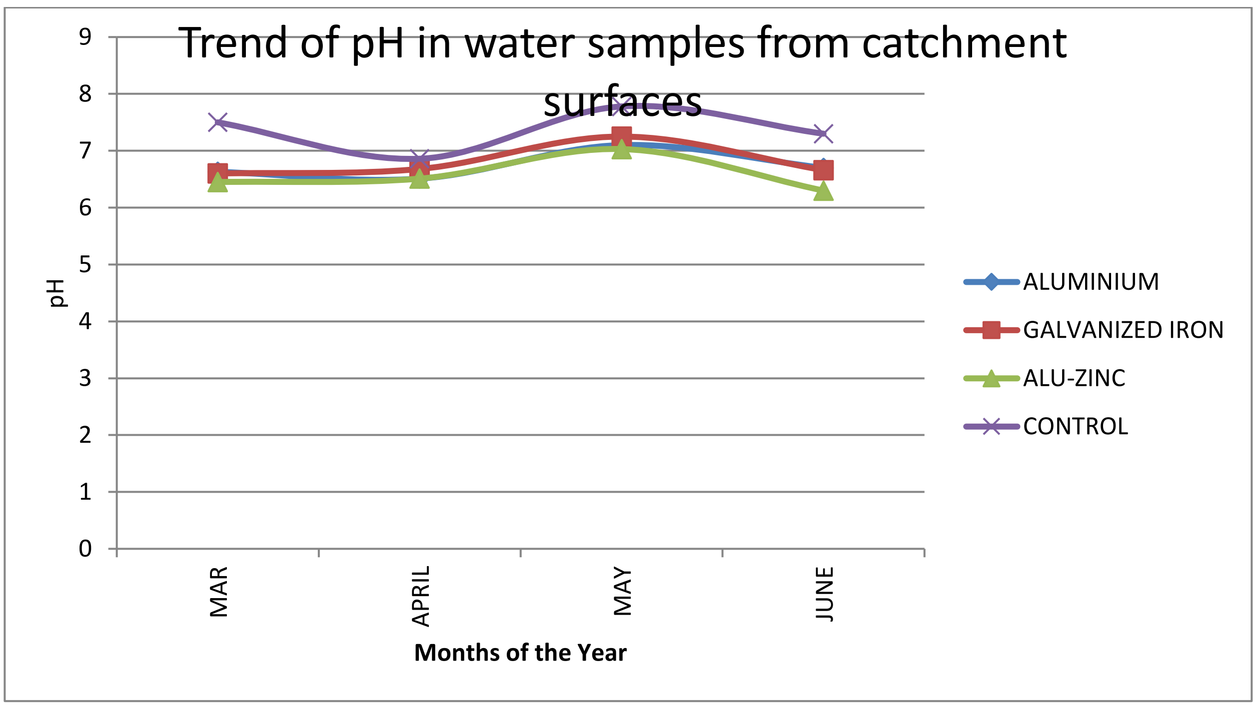

Figure 9: Trend of PH in water samples from catchment surfaces

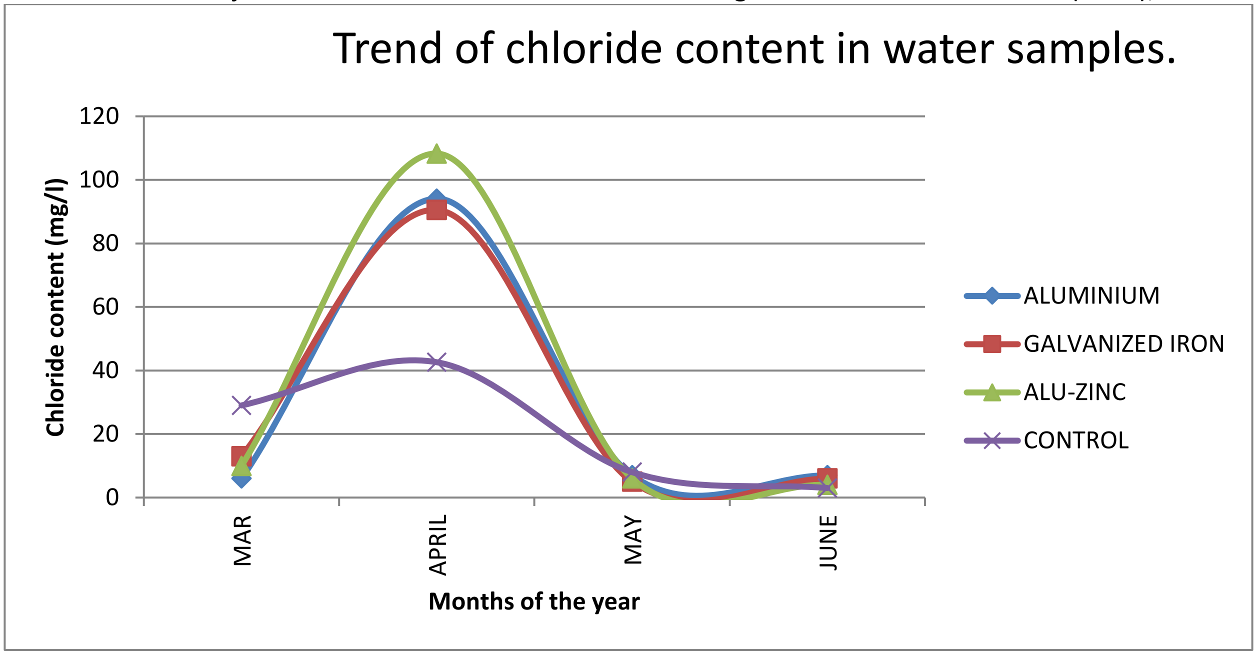

Figure 10: Trend of Chloride content in water samples from catchment surfaces

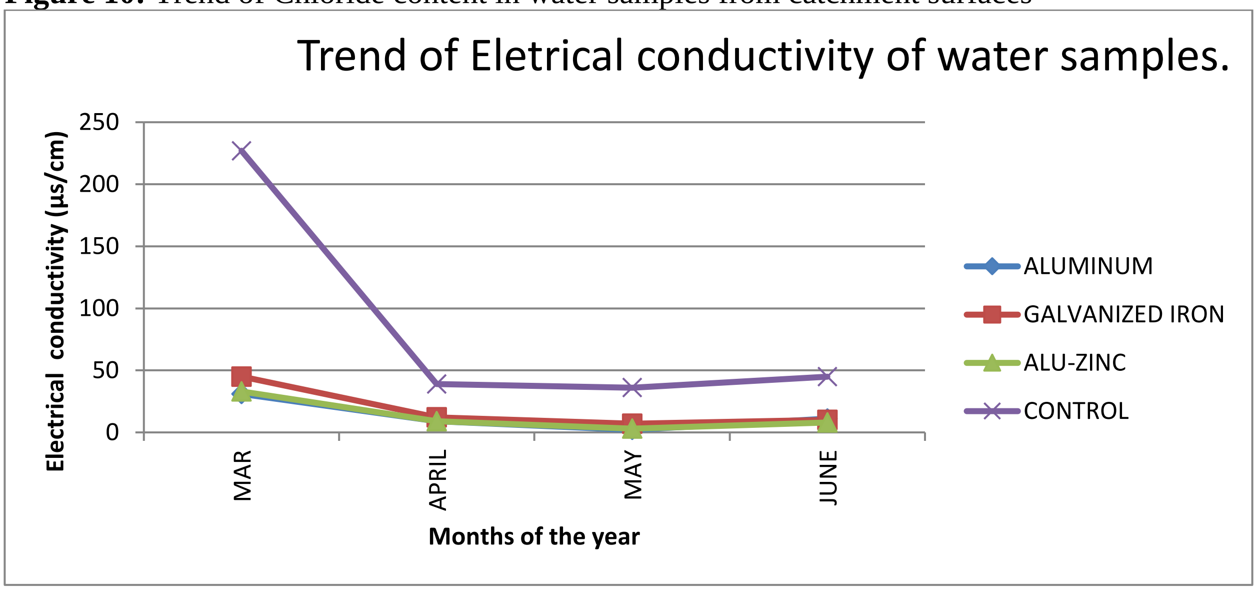

Figure 11: Trend of Electrical conductivity of water samples from catchment surfaces

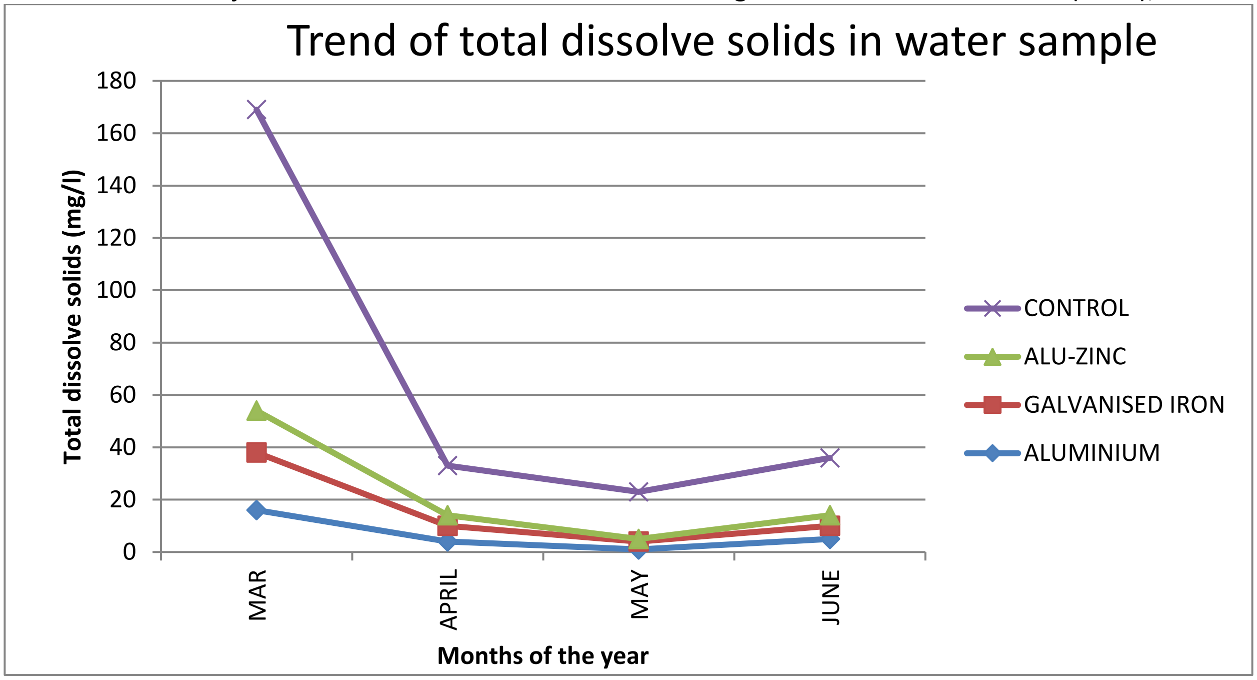

Figure 12: Trend of Total Dissolved Solids in water samples from catchment surfaces

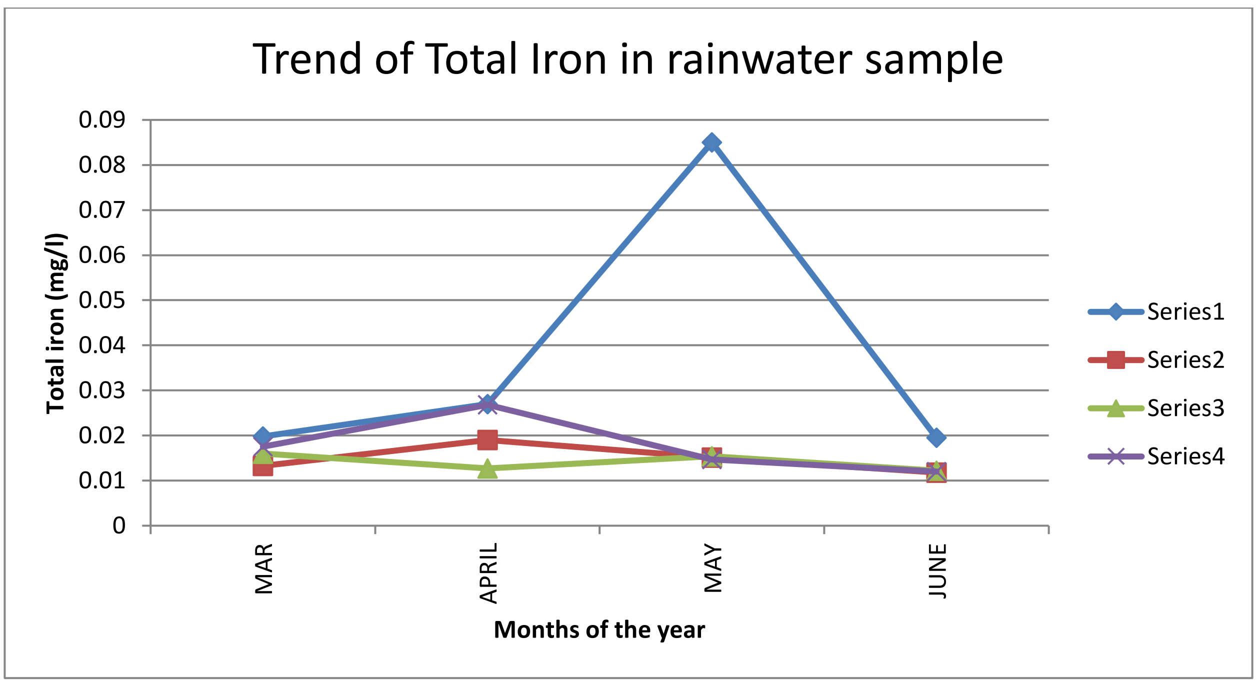

Figure 13: Trend of Total Iron in water samples from catchment surfaces

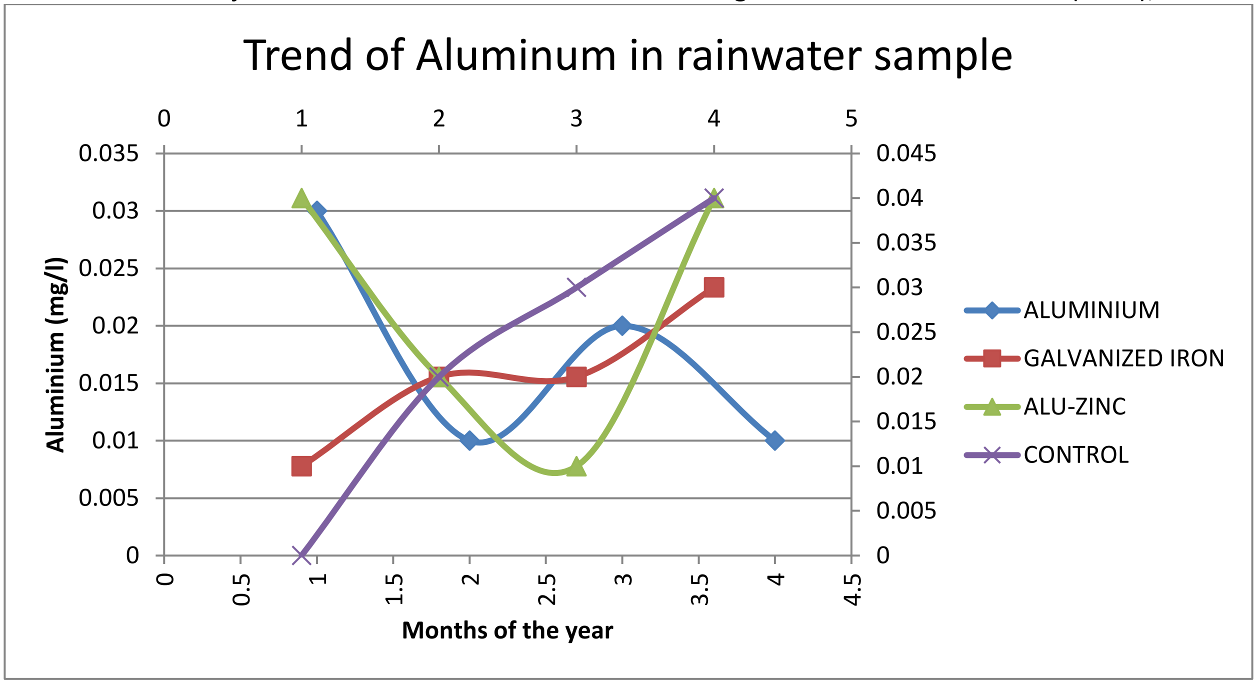

Figure 14: Trend of Aluminum in water samples from catchment surfaces

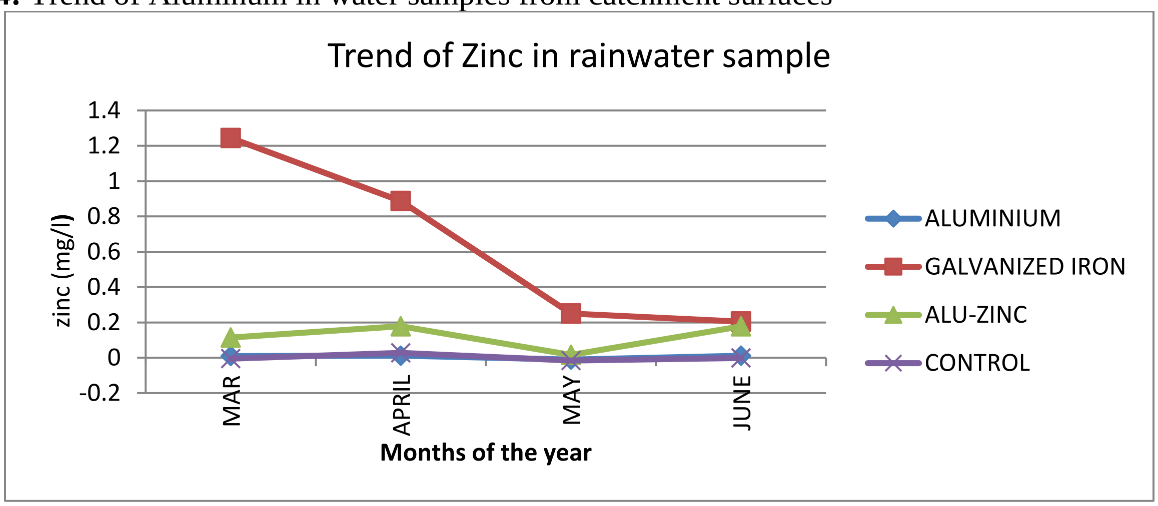

Figure 15: Trend of Zinc in water samples from catchment surfaces

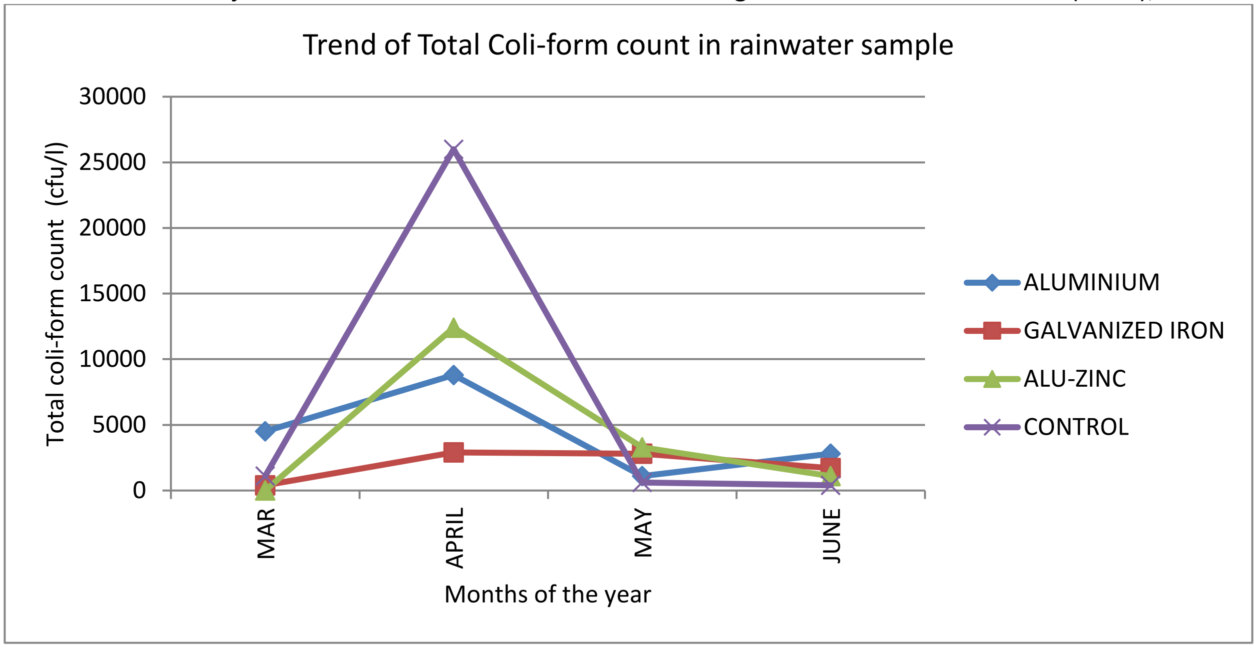

Figure 16: Trend of Total Coli-form count in water samples from catchment surfaces

Conclusion

Result obtained from the study indicates that, with the guideline from Standard Organization of Nigeria (SON), World Health Organization (WHO), Bureau of Indian Standard (BIS) and the European Union (EU), rainwater is safe for harvesting throughout the period of collection and the catchment surface in the area for domestic purpose. However, there is need for proper treatment for the Coli form count.

To meet up with the Government of Nigeria target of achieving 75% safe water coverage by 2020, capacities on appropriate choice of technology for rainwater harvesting should be strengthened especially technologies that do not rely on electricity. Harvested rainwater is therefore, recommended for the domestic use of inhabitants of Kotopo area of Abeokuta metropolis to reduce indiscriminate drilling of boreholes in the metropolis which could cause earthquake and over abstraction of ground water with attendant negative consequences.

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