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Rainwater Quality in Ibadan (Nigeria): Effect of Short Term Storage in Surface and Underground Tanks

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***Abstract*— Water is needed in adequate quality and quantity for human consumption. As population increases, demand for water is growing higher. Rainwater harvesting (RWH) is important for sustainable development and has no adverse environmental impacts. It also provides convenience in terms of decreased distance to sources of supply and is less time consuming than surface and groundwater sources. In this study, rainwater was collected from the rooftop and stored for a short term in underground and surface tanks. In total, 26 samples were collected from two RWH storage system. The stored samples were taken to the laboratory for Physico-chemical and biological analysis after days 1, 3, 7, 14, 21 and 28 respectively. Several parameters were included in the analysis: colour, temperature, turbidity, pH, total dissolved solids, total soluble solids, total hardness, alkalinity, dissolved oxygen, nitrate, total coliform and E. coli. The study reveals that the overall quality of water with respect to the WHO and Nigeria standards for drinking fell within the permissible limit. RWH system benefit from water and energy savings thus providing a system that is cost effective. The findings revealed that storage of rainwater in underground tank for a period of 28 days is fit for potable use with simple point-of -use treatment such as filtering and chlorination.**

***Index Terms*— Drinking water standard, Rainwater quality, Rainwater harvesting, storage system.**

I. Introduction

Water demand will increase substantially with population growth to meet the food demand and the economic growth [1]. By 2025, 60% of people will face water scarcity [2]. Developing countries like Nigeria are facing challenges of lack of safe drinking water due to inability to coordinate water policies with development activities.

In Nigeria, the water needs are met by surface and groundwater resources, which are ~226 billion m^3 and ~40 billion m^3, respectively [3]. Provision of potable water by the government to Nigerians has been very problematic. Water shortages are predominant in small towns, rural communities and even urban centers due to climate changes, distribution system losses, increasing demand and vandalism and funding constraints. Other factors include inadequate legislation, inefficient billing systems; poor tariff structure, aged and outdated equipment, inadequate power supply, poorly-trained and excessive man-power, poor operation and maintenance and lack of sustainability. Government instability has also led to lack of policy consistency in the water sector.

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RWH primarily consists of the collection, storage and subsequent use of captured rainwater, either as the principal or supplementary source of water. It is applicable both for potable and non-potable purposes [4]. Some systems can provide water for domestic, institutional, commercial and industrial purposes, as well as agriculture, livestock, ground-water recharge, flood control processes and as an emergency supply for fire-fighting [5-7]. RWH is a simple and ancient concept, which varies from small and basic systems of attaching a water butt to a rainwater downspout, to large complex systems of collecting water from many hectares to serve many people [8].
In comparison to the centralised system domestic rainwater harvesting is more cost effective, simple to manage and socially acceptable in most of the regions [9]. According to the World Health Organisation (WHO) rainwater is free from major impurities, though prone to mineral contamination from rooftop materials and microbial contamination from the faeces of birds [10-11]. However, this complication can be solved by simple point-of-use water treatment facilities like chlorination and filtering which were found to be the most cost-effective intervention to reduce waterborne disease like diarrhoea[12-13].

The rainwater harvesting potential for an urban city in Bangladesh was assessed using a multi-criteria decision analysis techniques [14]. Adecision support tool that can quantify the cost and benefit of implementing several RWH based storage systems (reinforced concrete tank, surface water reservoir and ground water recharge pits) was developed in Nigeria [15]. The Multicriteria-decision analysis model chose reinforced concrete tank as the most appropriate storage system for RWH.

In this study, the quality of domestic rainwater harvested from the rooftop was assessed for potable use. The average yearly rainfall data was analysed and rainwater samples were collected and stored for 1, 3,7, 14, 21 and 28 days respectively before being analysed for its physico-chemical and bacteriological parameters.

II. Study Area

Nigeria has a land mass of 923,768 km^2 with 36 States. Oyo State is in the south-west (longitude $3^0 45'$-$4^0 00'$E, latitude $7^0 15'$-$7^0 30'$N) and is reputed to be the largest City in Africa, south of the Sahara “Fig. 1”. Ibadan is the Capital of Oyo State with an estimated population of 2,559,853 in 2007 [16]. It is the second largest city in Nigeria in terms of land mass (400 km^2) [17]; consisting of 11 Local government areas “Fig. 1”.

Ibadan suffers serious water supply problems; cases of dry taps are common in virtually every part of the City. Children and women searching for water are common [18]. In this city, refuse dumps, pit latrines and open dumps are common and environmental sanitation is poor. Ibadan is a residential and urban area with an increasing population [19]. As population grows and urbanisation increases, more water is required and greater demand is made on both ground and surface water.

In Nigeria, the annual rainfall data varies from 0-2400 mm and the bulk of population lives in areas that receive just 0-1350mm [20]. There is more rainfall in the south and south-west than most other areas, whilst the north receives less (~800 mm). Rainfall data is often available from various sources such as the Meteorological office and Nigerian Airport Authority. The average monthly rainfall depths of Ibadan City are presented in “Fig. 2”.

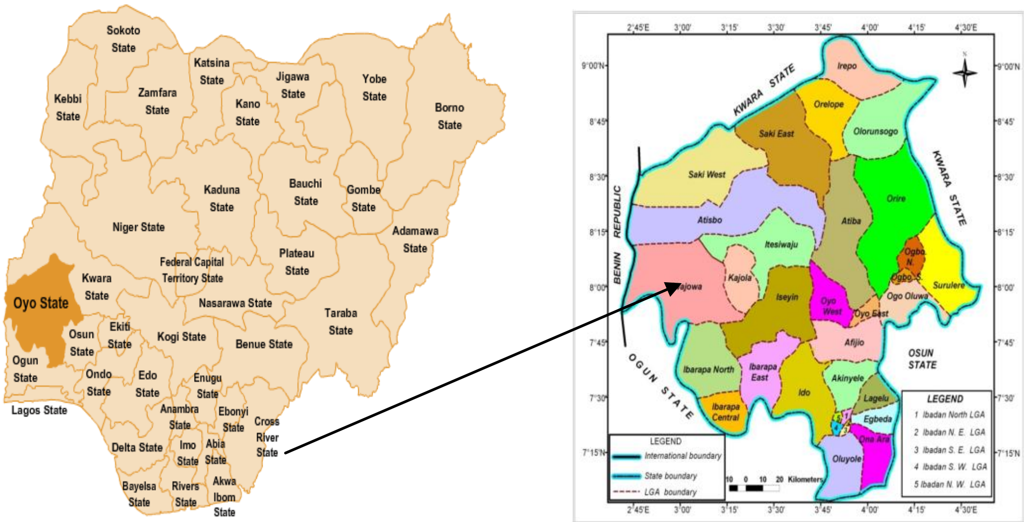

Fig. 1: Map of Nigeria showing Oyo state.
source:http://www.google.co.uk/search?q=map+of+nigeria+showing+oyo+state&source=lnms&tbm=isch&sa=X&ei=AqPyUdv6BuiN7Qa2n4GIBw&ved=0CAcQ_AUoAQ&biw=1366&bih=667#imgdii=_

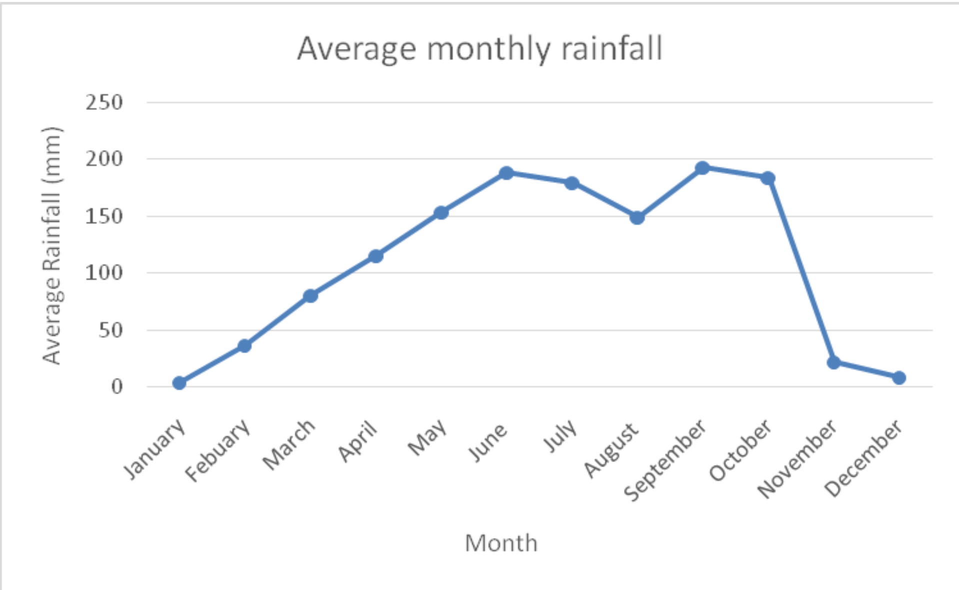

Fig. 2 Ibadan City Average Monthly Rainfall Pattern 1980 – 2009 [27]

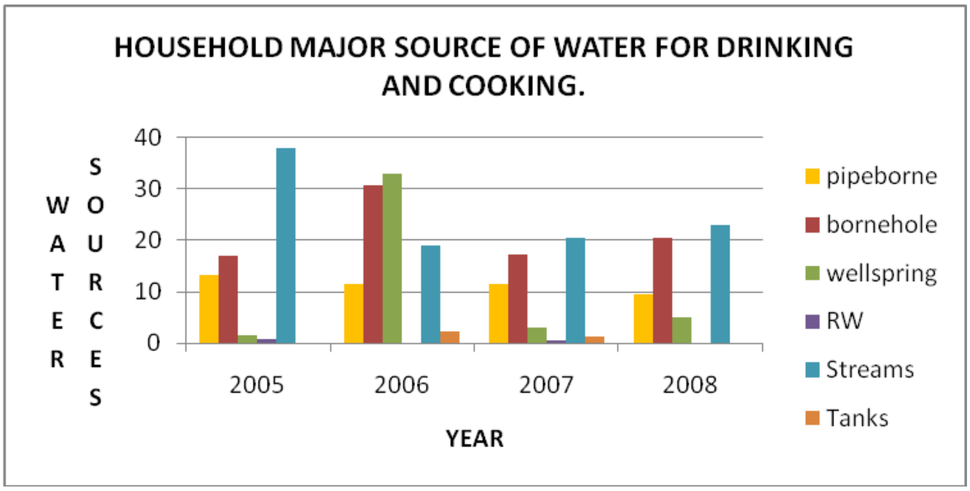

Fig. 3Water Sources in Ibadan (2005-2008)[28]

A. Water Sources

There is a challenge of lack of supply of pipe-borne water in Nigeria. Hence, many homes have wells sited around the house some distance from the septic tank.The scarcity of piped water has made communities find alternative water sources; groundwater sources being a ready source. Wells are a common groundwater source readily explored to meet community water requirements or address shortfalls [21]. The most common cause of pollution is attributed to the proximity of septic tanks to wells and unhygienic use of wells.

Groundwater pollution is also caused by the disposal of solid or liquid wastes in pits, abandoned boreholes or even stream channels and landfills [22]. These processes result in the deterioration of the physicochemical and biological properties of water [23].Hence, there is insufficient excellent quality water for drinking, due to high pollution rates of groundwater sources [24]. The cost of developing surface water is very prohibitive, due to poor management of wastes, which are usually dumped into streams and other surface waters.

Public drinking water is often unreliable in Nigeria [25]. Some 52% of Nigerians do not have access to improved drinking water supply [26]. There is inadequate supply of treated pipe-borne water to communities, due to lack of proper maintenance of water treatment plants. However, the demand for potable water met by pipe-borne water is very small “Fig. 3”. Hence, there is a need to tap other sources of water to meet requirements.

III. MATERIALS AND METHODS

The methods used in this study is presented in “Fig. 4”.

B. Sampling

The sampling of rainwater was performed twelve times with sterilised 75 CL polyethylene bottles “Plate 1”. The bottles were sterilized with distilled water before collection of rainwater samples. The rainwater collected were stored in surface and underground tanks before been taken for analysis in the laboratory at intervals of 1, 3, 7, 14, 21 and 28 days respectively. In the case of the surface tank, samples were collected 6 times from sampling point as shown in “Plate 2”, between October and November 2015. For the underground storage tank, samples were collected from sampling point as shown in “Plate 3”. A total of 26 samples were analysed by a research laboratory at the Department of Epidemiology, University College Hospital, Ibadan. The surface and underground tanks were also sterilized with distilled water before collection to avoid physical, chemical and bacteriological contamination of the samples.

C. Sample Preservation

Samples were collected from the storage tanks at intervals of days, preserved in the refrigerator before been transported to the laboratory for testing. This is to prevent growth of micro-organisms.

D. Laboratory Analysis

The parameters to be analysed were taken from WHO standard for drinking water. The drinking water standards consist of 109 parameters. In this study, 13 of the original parameters were analysed; a summary of the analytical parameters and drinking water standards (WHO and Nigeria standard; FEPA, SON) were shown in “Table I”.

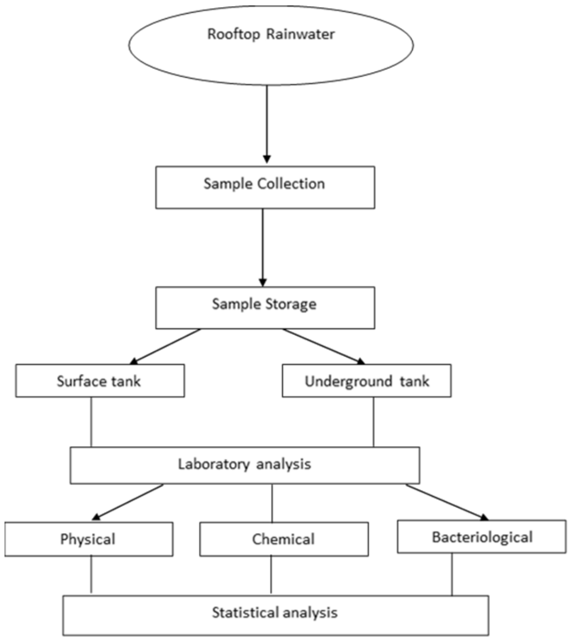

Fig. 4 Flow Chart of Methodology

Plate 1 Rainwater Samples

Plate 2 Surface Tanks

Plate 3 Underground Tanks

Table I Physico-chemical and bacteriological standards for drinking water

Parameter	WHO	FEPA	SON
Colour (Hazen)	5.0	15	15
Temperature (^{0}C)	-	-	-
Turbidity (NTU)	5.0	1.0	5.0
pH	6.5-8.5	6.5-8.5	7.0-8.0
Conductivity (μs/cm)	-	-	1000
TDS (mg/l)	500	500	500
TSS (mg/l)	-	-	-
Total hardness (mg/l)	100	200	150
Alkalinity (mg/l)	-	-	-
Dissolved oxygen (mg/l)	-	-	-
Nitrate (mg/l)	10.0	10.0	10.0
Total coliform (MPN)	10	-	10
E.coli (MPN)	0	0	0

III. RESULTS AND DISCUSSION

E. Analysis of Rainwater Quality

The results of the physio-chemical and bacteriological analyses of the rainwater samples stored in underground and surface tanks at Days 1, 3, 7, 14, 21 and 28 respectively were presented in "Tables II-VII". All parameters were compared to the WHO, FEPA and SON standard for drinking water. Most parameters met the standard except TSS, alkalinity and DO in surface and underground tank samples which were a little bit above the permissible limit. The colour ranges from 3.4 on Day 1 to 3.8 on Day 28 in the surface tank given a mean average of about 3.5. The temperature was between 19.2 0C and 20.8 0C. There was no turbidity reading except on Day 1 of the rainwater sample stored in the surface tank (0.02 NTU). The pH ranged from 6.62 - 7.36, while the electrical conductivity and total dissolved solids increased consequently from samples in Day 1 to samples in Day 3.

The value obtained for the TSS at Day 1 was 0.035 mg/l and 0.74 mg/l at Day 28, the sample from underground tank has the highest TSS of 1.6 on Day 7. The total hardness increased from 68 mg/l at Day 1 to 96 mg/l at Day 28 as well as the alkalinity varying from 8 mg/l at Day 1 to 52 mg/l at Day 28. The DO was quite steady ranging from 7.3 - 7.79mg/l. The Nitrate readings were relatively low ranging from 0.0049 - 0.0359 mg/l.

The total coliform in the samples stored in underground tank reduces gradually from 17 MPN at Day 1 to 4 MPN at Day 28. For samples in surface tank it varies from130 MPN at Day 1 to 26 MPN at Day 28. The E. coli result in the surface tank was highest at Day 28 with a value of 17 MPN.

Table IIPhysico-chemical and bacteriological parameters at Day 1

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.4	3.5
Temperature (^{0}C)	20.8	20.8
Turbidity (NTU)	Nil	0.02
pH	7.10	7.18
Conductivity (μs/cm)	1.15	1.50
TDS (mg/l)	0.69	0.85
TSS (mg/l)	0.036	0.035
Total hardness (mg/l)	68	72
Alkalinity (mg/l)	12	18
Dissolved oxygen (mg/l)	7.39	7.74
Nitrate (mg/l)	0.028	0.0317
Total coliform (MPN)	17	11
E. coli (MPN)	2	2

Table IIIPhysico-chemical and bacteriological parameters at Day 3

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.6	3.4
Temperature (^{0}C)	20.5	20.4
Turbidity (NTU)	Nil	Nil
pH	7.36	7.13
Conductivity (μs/cm)	0.59	0.52
TDS (mg/l)	0.35	0.31
TSS (mg/l)	1.45	1.55
Total hardness (mg/l)	84	88
Alkalinity (mg/l)	12	8
Dissolved oxygen (mg/l)	7.75	7.75
Nitrate (mg/l)	0.0184	0.0140
Total coliform (MPN)	170	130
E.coli	3	2

Table IVPhysico-chemical and bacteriological parameters at Day 7

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.5	3.6
Temperature (^{0}C)	20.8	20.8
Turbidity (NTU)	Nil	Nil
pH	7.36	7.13
Conductivity (µs/cm)	35.2	30.4
TDS (mg/l)	20.7	18.23
TSS (mg/l)	1.6	1.45
Total hardness (mg/l)	96	120
Alkalinity (mg/l)	8	8
Dissolved oxygen (mg/l)	7.75	7.79
Nitrate (mg/l)	0.0157	0.0114
Total coliform (MPN)	2	33
E.coli	2	6

Table VPhysico-chemical and bacteriological parameters at Day 14

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.5	3.7
Temperature (^{0}C)	19.2	19.2
Turbidity (NTU)	Nil	Nil
pH	6.78	6.62
Conductivity (µs/cm)	31.2	29.6
TDS (mg/l)	18.63	17.77
TSS (mg/l)	0.4	0.65
Total hardness (mg/l)	96	116
Alkalinity (mg/l)	12	12
Dissolved oxygen (mg/l)	7.76	7.76
Nitrate (mg/l)	0.0445	0.0035
Total coliform (MPN)	34	130
E.coli	6	15

Table VIPhysico-chemical and bacteriological parameters at Day 21

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.2	3.4
Temperature (^{0}C)	19.7	19.6
Turbidity (NTU)	Nil	Nil
pH	6.68	6.68
Conductivity (µs/cm)	33.0	29.6
TDS (mg/l)	19.78	17.73
TSS (mg/l)	0.6	0.65
Total hardness (mg/l)	88	92
Alkalinity (mg/l)	16	12
Dissolved oxygen (mg/l)	7.75	7.75
Nitrate (mg/l)	0.0359	0.0090
Total coliform (MPN)	4	4
E. coli	4	4

Table VIIPhysico-chemical and bacteriological parameters at Day 28

Parameter	Underground tank	Surface tank
Colour (Hazen)	3.7	3.8
Temperature (^{0}C)	19.4	19.6
Turbidity (NTU)	Nil	Nil
pH	7.14	7.22
Conductivity (µs/cm)	29.4	30.1
TDS (mg/l)	17.65	17.98
TSS (mg/l)	0.71	0.74
Total hardness (mg/l)	86	96
Alkalinity (mg/l)	52	24
Dissolved oxygen (mg/l)	7.79	7.79
Nitrate (mg/l)	0.0049	0.0062
Total coliform (MPN)	4	26
E. coli	4	17

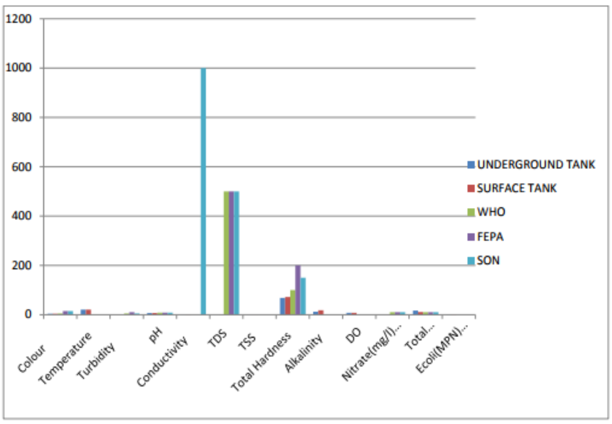

Fig. 5Rainwater Parameters at Day 1

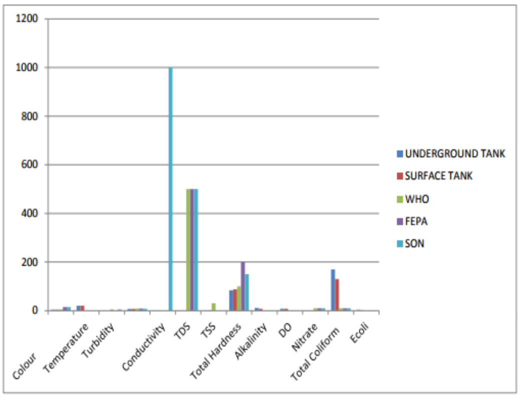

Fig. 6 Rainwater Parameters at Day 3

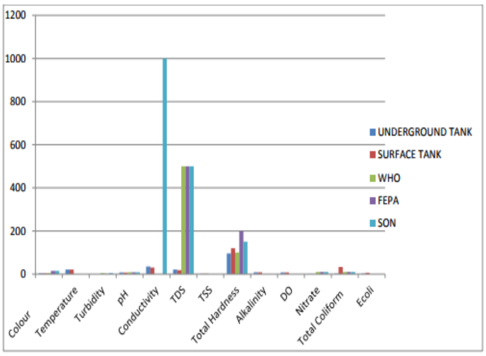

Fig. 7 Rainwater Parameters at Day 7

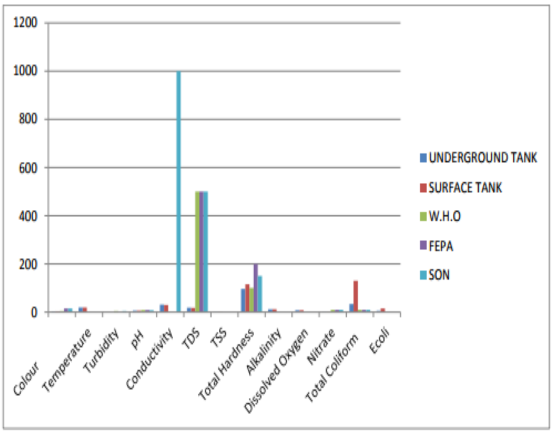

Fig. 8 Rainwater Parameters at Day 14

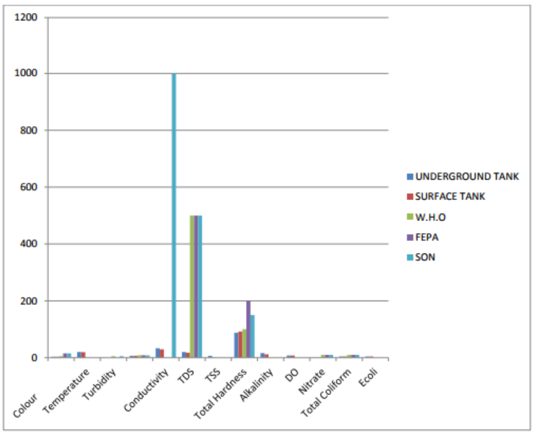

Fig. 9 Rainwater Parameters at Day 21

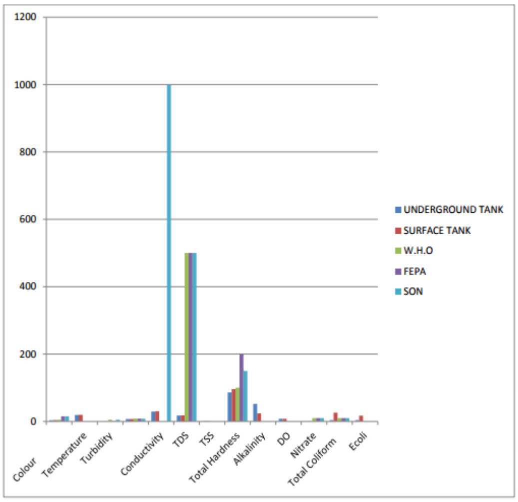

Fig. 10 Rainwater Parameters at Day 28

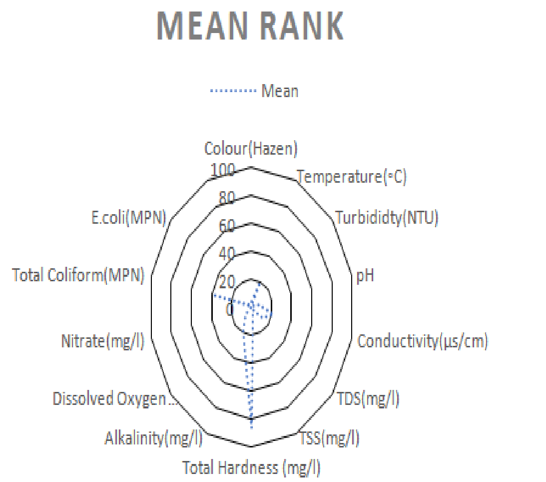

Fig. 11 Mean Characteristics of Rainwater Sample in Underground Tank

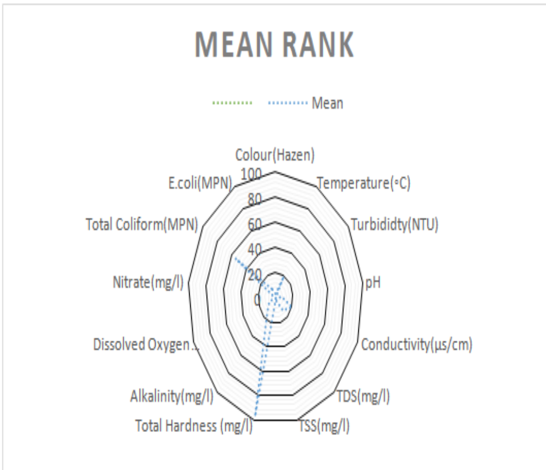

Fig. 12 Mean Characteristics of Rainwater Sample in Surface Tank

F. Comparison of rainwater samples with standard for drinking water

The parameters of rainwater stored in underground and surface tanks were compared with WHO, FEPA and SON standard for drinking water. The colour fall between the permissible limit which makes it suitable for domestic use such as laundering and dyeing as presented in “Figs. 5-10”.

The electrical conductivity falls within the safe limit (WHO, FEPA, SON standards) indicating that the stored rainwater is fit for drinking purposes. The TDS and TSS parameters fall within the WHO and Nigerian drinking water standards. The sampled rainwater was free to an extent of suspended solids, TSS obtained were either from the atmosphere or from the roofing sheet. This can be removed by water filtration.

The total hardness for the rainwater samples stored in underground and surface tanks gradually increased as the samples spent days in the storage tanks. The rainwater stored in underground tank is moderately hard as values fall within 50 -150 mg/l while the total hardness of rainwater stored in surface tank is slightly higher due to the impact of heat. Increase in temperature has adverse effect on the surface tank; at Day 14, total hardness has exceeded the WHO safe limit although within the FEPA and SON permitted limit. The Nitrate level in the stored rainwater samples fall within the safe limit for drinking water indicating low level of wastes and chemical fertilizers in the water. Water suitable for human consumption should be free from disease causing and non-pathogenic organisms. Coliforms are a type of bacteria found in the environment, most coliforms are relatively harmless and can be treated with chlorine. The laboratory analysis indicates a relatively elevated level of total coliform which is quite higher than the recommended standard for drinking water. This may be due to the presence of faeces of birds on the rooftops. This implies that rainwater requires a first flush devise of 10-15 minutes before collection to ensure than faecal wastes on the rooftops are flushed off before collection. Hence, for rainwater to be suitable for drinking purpose, little treatment such as filtering and treatment with chlorine is required.

The mean value of colour in surface as compared to underground tank is presented in “Figs. 11and 12” respectively. The rainwater sample in underground tank was found to be less colourless, same applies to turbidity, TSS, TDS, total hardness, DO, total coliform and E. coli parameters with mean values lower than that of surface tank. This may be due to lower temperature in underground tank thus reducing bacteria growth and presence of oxygen. The pH values for the samples in underground tank as presented in “Fig. 11” makes it suitable for drinking purpose unlike the pH value of rainwater sample in surface tank which falls in the acidic range.

Although the Nitrate level of rainwater stored in underground tank is slightly higher than that of surface tank as presented in “Fig. 12”, due to the presence of chemical fertilizers. The rainwater stored in underground tank is still suitable for drinking purposes provided it undergoes water treatment processes such as filtering and chlorination.

IV. CONCLUSION

This paper focus on the assessment of the quality of harvested rooftop rainwater for potable purpose. Rainwater were collected from rooftop in Ibadan and stored in underground and surface water tanks for 1, 3, 7, 14, 21 and 28 days respectively. Laboratory analysis was carried out on the rainwater samples to determine the physico-chemical and bacteriological properties. Several parameters were included in the analysis: colour, temperature, turbidity, pH, total dissolved solids, total soluble solids, total hardness, alkalinity, dissolved oxygen, nitrate, total coliform and E. coli.

The results were compared with WHO and Nigeria standards for drinking water. The study revealed that the overall quality of water with respect to the W.H.O and Nigeria standards for drinking fell within the permissible limit. The findings revealed that storage of rainwater in underground tank for a period of 28 days is fit for potable use with simple point-of -use treatment such as filtering and chlorination.

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