A Low Cost 'Umbrella Rainwater Harvester' for Open Air Markets in Nigeria: Design, Fabrication, Yield and Quality Assessment

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Abstract - Thousands of traders under umbrella shades in Nigerian markets have no safe water, hygiene or sanitation. There is therefore a great need to develop a simple and low cost device for harvesting rain water in the markets. Two umbrellas of diameters 1.2m and 1.9m were sourced locally and used to fabricate a rainwater harvester. Water samples from rainwater harvested by this harvester, roofs with galvanized iron sheets and the rain collected directly into a container from open space were analysed for physicochemical and microbiological parameters using standard laboratory methods. Harvestable rain water and rainfall intensity were correlated. A cost-benefit analysis and key informant interviews (KII) were carried out to assess the efficacy of the umbrella harvester and its acceptability by Nigerian traders. Physicochemical and bacteriological parameters of water samples harvested by the umbrella harvester were comparable significantly to those obtained in open space. They were however, different from those obtained from the galvanized roofs as shown below (umbrella harvester, open space and galvanized roof, respectively) : pH (6.42±0.30 Vs. 6.31±0.24 Vs. 6.48±0.46), electrical conductivity (40.79±9.25 Vs. 41.48±2.35 Vs. 52.43±2.35) µS/cm, total dissolved solids (32.97±2.82 Vs. 32.73±2.45 Vs. 41.67±2.10) mg/L, total suspended solids (0.82±0.72 Vs. 0.93±0.14Vs. 4.02±0.68) mg/L, total coliform count (MPN per 100 ml sample 0.00±0.00 Vs. 0.33±0.82 Vs. 97.83±12.03), and total heterotrophic plate count (cfu per ml sample, 0.00±0.00 Vs. 0.00±0.00 Vs. 60.17±94.58). All the physicochemical parameters in all the samples were within the WHO limits. The cost-benefit analysis showed that the derivable benefits overweigh the cost in terms of regular safe water availability, savings from buying water from vendors, and improved health benefits due to safe water. All the market leaders agreed that this innovation was viable and reliable and they were ready to utilise the umbrella rain harvester.

Index Terms: Umbrella rain harvester, Nigerian markets, Water quality, Coliform count, Traders, Rainfall intensity, Water availability

1 INTRODUCTION

WATER is an indispensable resource for human subsistence. Though it covers about 70% of earth's surface, just 2.5% of it is available for biological use. Water may be grouped into atmospheric, surface, and ground water where atmospheric water includes moisture contained in the cloud [1] which precipitates as snow and rain [2]. Rain water is a form of precipitation in which liquid water falls to the earth's surface and both rainwater and snowmelt are widely regarded as the primary sources of all drinking water on this planet [3].

Lack of safe and adequate water supply, basic sanitation and hygiene practices are associated with high morbidity and mortality due to high rate at which enteric and water borne diseases are spread [4]. Millions of people throughout the world do not have access to clean water for domestic purposes and conventional piped water is either absent, unreliable or too expensive in many developing countries [5]. In 2004, the World Health Organization (WHO) and the United Nations International Children Education Fund (UNICEF) estimated that 80% of all illness in developing countries was linked to water and sanitation [6]. It was recently estimated that about 1.1 billion people globally did not have access to improved water supply sources whereas 2.4 billion people did not have access to any type of improved sanitation facility [7].

Although the World population access to improved water has increased to 87%, only 58% of Nigerian population has access to water [8]. Also in Nigeria, most markets are characterized by unsanitary conditions, including poor water supply, poor drainage systems, unsanitary waste disposal, and overcrowding, resulting in poor personal and environmental hygiene. Infants and young children of the Nigerian market women are constantly exposed to health hazards associated with such an unsanitary environment, resulting in health conditions like diarrhoea and other water-borne diseases. The risk factors in the occurrence of these diseases among the under five of these have been identified to be water and food bought from vendors, child defecation practices, mothers' cleaning up practices after child's defecation, and refuse-disposal practices [9].

One of the features of Nigerian markets is "markets within markets". This implies many formal stall owners sublet a small space for other smaller traders who starts trading under an umbrella which protects them from rain and shine. These traders suffer from lack of sanitary facilities and faced with heat-related illnesses [10]. During torrential rainfalls, these roadside traders are exposed to cold which has several adverse effects. It has been

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documented that the hand washing and sanitation practices among roadside traders in Nigeria is very poor due to the unavailability of water for their sanitation [9]. There is therefore a great need to develop a simple device such as an umbrella rainwater harvester that can serve a dual purpose of providing shade under the sun and shelter during the rain fall. This paper described such a novel design of umbrella serving dual purposes of providing shade and also collect water of improved quality during the rainy season.

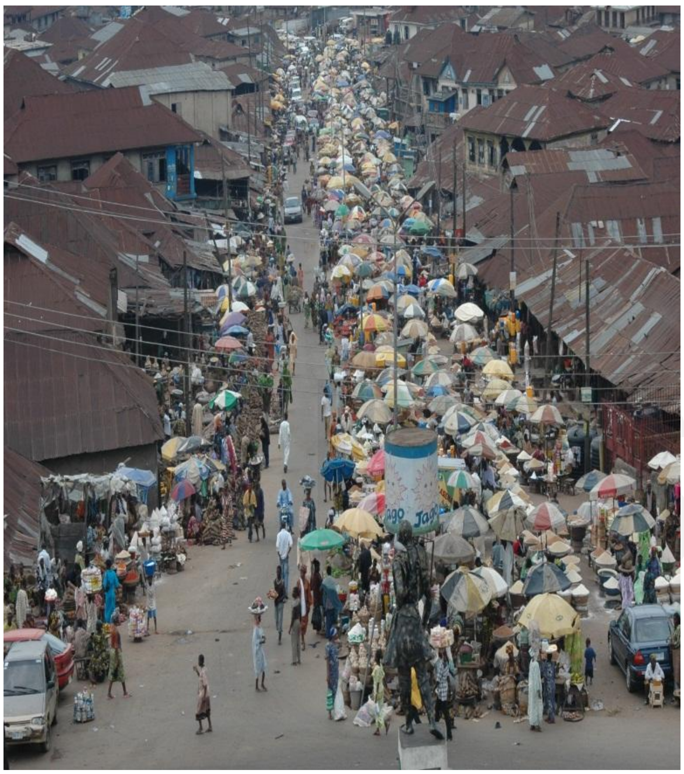

Fig. 1. City of Ibadan showing road-side markets

2 MATERIALS AND METHODS

2.1 Description of the Study Area

This study was conducted in Ibadan which is the capital city of Oyo State, Nigeria with a land mass of 400 km2 [11]. It is characterised by an elevation of 210m above the sea level, isolated ridges and peaks, rising to an elevation of 274m. It is located in the South-west of Nigeria (longitude 3045'-4000'E, latitude 7015'-7030'N) and is reputed to be the largest City in Africa, South of the Sahara. Ibadan has an estimated population of 2,559,853 in 2007 [12] and a projected population of 7,656,646 in 2015. It falls within the humid forest zone of Nigeria with great potential of rainfall and has a tropical wet and dry climate and relatively constant temperatures throughout the year. The rainy period is usually between April and October and the average annual rainfall is between 1100 - 1400mm spreading over an average of between 90-120 days annually. Ibadan is used to be the social, educational, commercial (Fig. 1), industrial and administrative centre of the then western state (now Oyo, Ogun, Ondo and parts of Lagos and Bendel). It is now the capital of Oyo state and has direct link with many urban centres as well as rural areas by a network of roads, railways and air routes.

2.1 Methods of Data Collection

The instruments used for the data collection were: observation checklist for design and fabrication of umbrella rain water harvester, rainwater collection, laboratory analyses (physicochemical and bacteriological analyses of water samples), physical observation for quantity of rainwater that can be harvested by the umbrella and cost-benefit analysis, using specified equations, and Key Informant Interview (KII) guide.

2.2 Design and Fabrication of Umbrella

Two umbrellas of diameters 1.2m and 1.9m were sourced locally and used to fabricate a rainwater harvester. The smaller umbrella had its tip sawed off, revealing the hollow tube in the umbrella. A flexible hose of diameter 1cm and length 2 m was attached firmly to the smaller umbrella which was then inverted and fixed on the normal hyperbolic shaped 1.9m umbrella. The flexible hose which was covered at the opening with a sieve was inserted into the hollow of the bigger umbrella and directed into a storage tank. A metal or wooden cupboard of length 0.42m, breadth 0.33m and height 0.44m was fabricated to serve a dual purposes of providing solid base for the harvester and compartment that houses a 25L water storage keg into which the flexible hose is connected (Fig. 2 and Fig. 3).

2.3 Rainwater Collection

Three sources of rainwater were collected for water quality assessment;

Rainwater from the sky

Rainwater from the umbrella rainwater harvester

Rainwater from a building roofs with galvanized iron

The rainwater was collected from the sky during rainfall by placing a sterile/clean container, an open plastic pail, outside in the open. The container was placed 1.5 meters above the ground to avoid rain splash. Samples were also taken from water collected from gutter of a building roofs in the same location (15mins after rain fall started to allow proper washing of the catchment surface) and the storage thank of the umbrella.

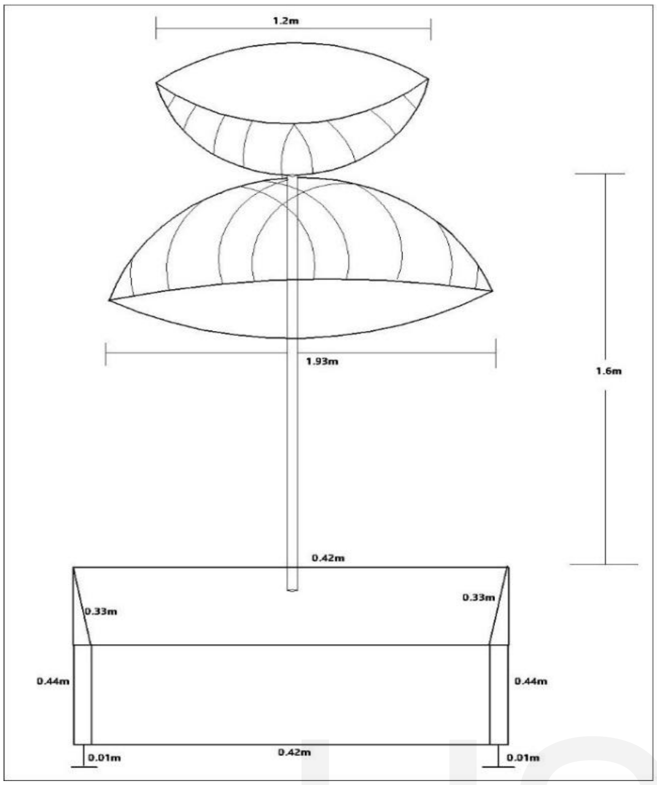

Fig. 2. Schematic diagram of umbrella rainwater harvester

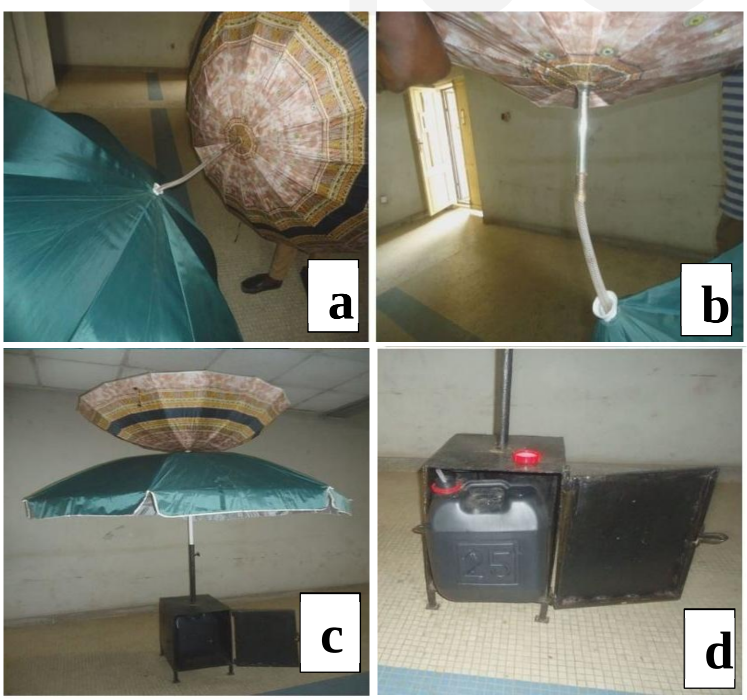

Fig. 3. Assemblage of the harvester: a) - 2 umbrellas being connected; b) - connection hose; c) - the set up and d) - water storage tank.

2.4 Physicochemical and Bacteriological Analyses of Water Samples

All the water samples were analysed for physicochemical and bacteriological parameters in order to determine the efficacy of the umbrella rainwater harvester. The physicochemical parametersanalysed included: pH, electrical conductivity, total hardness, calcium hardness, chloride, nitrate, alkalinity, Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). Conductivity and TDS were determined using an electrical conductivity meter (470 Jenway Conductivity Meter) while the rest of the parameters were determined following the methods described by American Public Health Association [13]. The E.coli determination in the water samples was carried out by multiple tube fermentation and results obtained were expressed in terms of MPN (Most Probable Number), which is based on certain probability formulae [13].

2.5 Rain Water assessment and Cost-benefit Analysis

Assessments of quantity of rainwater that can be harvested by the umbrella per a rainfall episode and cost-benefit analysis of using the umbrella rainwater harvester were also carried out through observation and specific formulae. To determine the quantity of rainwater harvestable per rainfall episode, the following formula was used:

$$\boldsymbol{Q} = \boldsymbol{RC} \times \boldsymbol{R} \times \boldsymbol{A}$$

Where:

Q = quantity of water that runs off (L)
RC = runoff coefficient
R = total rainfall (mm)
A = catchment area (m2)

For the cost-benefit analysis, the financial and health-status aspects were considered. Total cost expended in fabricating the umbrella harvester was compared to the expected lifespan of the harvester and the total amount that would have been used by the traders to purchase water from water-vendors had the harvester not been used for the period of that lifespan [14]:

$$\frac{Cost\ of\ an\ umbrella\ rainwater\ harvester}{Annual\ cost\ of\ purchasing\ water \times Expected\ lifespan}$$

Considering health-status, the cost-benefit analysis was estimated in view of the improvement in hygiene practices, the number of water-related diseases that would have been avoided and the amount that would have be spent for curative purposes by the users had they not utilised the umbrella.

2.6 Key Informant Interview (KII)

A total of six KIIs were conducted for the heads of market traders association and representatives of cleaners at two popular markets in Ibadan (Gbagi and Oje markets). Tape-recorded information from the KIIs was transcribed and analysed manually using thematic approach. Quantitative data were analysed using descriptive statistics to get mean values and standard deviation ANOVA to compare the means of the various rainwater sources at 5% level of significance.

3 RESULTS AND DISCUSSION

3.1 Physicochemical and Bacteriological Analyses of Water Samples

The results obtained for both physicochemical and bacteriological analyses were compared with WHO and SON guideline limits as presented in Tables 1 and 2. The mean pH and calcium hardness of the rainwater from the umbrella harvester and open space were: 6.42 ± 0.30Vs. 6.31± 0.24 and 5.17 ± 1.47 mg/L Vs. 3.33 ± 1.36 mg/L respectively which were within the guideline limits. The mean pH of the rainwater samples from all the sources (raw rainwater, from harvester, storage keg and domestic rainwater harvester) values were slightly acidic in nature, ranging from 6.31± 0.24 to 6.48 ± 0.46. This agrees with the findings of a study by Shittu et al. [15] where the pH of rainwater was reported to be slightly acidic. According to Ahipathy and Puttaiah [16], pH of natural water is an important factor that determines the suitability of water for various purposes, including toxicity to animals and plants. Also, the dissolved carbon dioxide in the atmosphere as the rains fall contributes to the slightly acidic nature of the water [17] and any trace of Nitrates or Sulphates dissolved in the air would further reduce the pH [18].

The results of other parameters, viz. electrical conductivity, alkalinity, chloride, hardness, nitrate, total dissolved solids and total suspended solids also fell below the maximum limits specified in the guidelines. Generally, there were no significant differences in the parameters in the rainwater from the open space and water from the harvester (Table 1). Electrical conductivity of the rainwater samples for the umbrella (40.79 ± 9.25 µS/cm) and that collected from the open space (41.48 ± 8.23 µS/cm) were in line with the findings of a similar study by Achadu et al. [19]. Electrical conductivity of water is a useful and easy indicator of its salinity and total salt content. It indicates the presence of ions within the water and is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium, iron and aluminum [20]. The slightly high alkalinity values in the water samples could be due to neutralization of the acidity by soil dust components like Ca and Mg as was reported in the finding of Umesh et al. [21]. It is a measure of the capacity of the water to neutralize acids and reflects its inherent resistance to pH change [22].

TABLE 1
PHYSICOCHEMICAL ANALYSIS OF WATER SAMPLES FROM THE UMBRELLA AND OTHER TWO SOURCES

Parameter (unit)	Raw rain water from open space	Sampes from galvanized Roofs	Rainwater from the Umbrella Harvester	WHO standards[25]	SON standards [26]
pH	6.31±0.24a	6.48±0.46b	6.42±0.30a	6.5-8.5	7.0-8.0
Electrical Conductivity (µS/cm)	41.48±8.23a	52.43±2.35b	40.79±9.25a	900	1000
Chloride (mg/L)	11.77±1.27a	19.42±2.37b	11.97±2.66a	250	250
Total Alkalinity (mg/L)	14.32±2.72a	21.53±2.33b	15.75±2.52a	100	100
Total Dissolved Solids (mg/L)	32.73±2.45a	41.67±2.10b	32.97±2.82a	500	500
Total Suspended Solids (mg/L)	0.93± 0.14a	4.02±0.68b	0.82±0.72a	NS	NS
Total Hardness (mg/L)	7.83±1.32a	36.33±4.08b	10.67±1.51a	100	150
Calcium Hardness (mg/L)	3.33±1.36a	21.50±2.43b	5.17±1.47a	NS	NS
Nitrate (mg/L)	1.49±0.58a	5.38±0.72b	1.58±0.43a	10	10

NS- Not specified; values with different letters (a and b) along the rows are significantly different (p=0.05, n = 4)

Results of the mean total dissolved solids of all samples, ranging between 0.82 ± 0.72 and 4.02±0.68 are in agreement with a similar study by Okoye et al. [23]. Presence of high total suspended solids in water has the ability to reduce the amount of light penetrating into the water body. According to Efe [24], classification of water in terms of softness and hardness can be made in considering the following schemes: 0-50 soft; 50-100 moderately soft; 100-150 moderately hard; 250-above hard. This classification shows that all the rainwater samples harvested were in soft water categories.

There was a significant difference in the mean electrical conductivity and alkalinity of the samples of rainwater collected by the umbrella harvester and galvanized roofs: 40.79 ± 9.25 µS/cmVs. 52.43 ± 2.35µS/cm and 15.75 ± 2.52 mg/L Vs. 21.53 ± 2.33 mg/L, respectively. This shows that the harvester is more effective in obtaining better quality water than ordinary galvanized roofs. Also, the variations in other parameters for harvester and the galvanized roofs such as: chloride level (mg/L) (11.97 ± 2.66 Vs. 19.42 ± 2.37); total hardness ($CaCO_3$, mg/L) (10.67 ± 1.51 Vs. 36.33 ± 4.08) and calcium hardness (mg/L) (5.17 ± 1.47 Vs. 21.50 ± 2.43), respectively. However, all of the above mean values were within the guideline limits recommended by the national regulatory bodies.

As shown in the Table 2, the mean total coliform counts of the rainwater from umbrella harvester and the open space were 0.00 ± 0.00 MPN/100mlVs. 0.33 ± 0.82 MPN per 100ml while the mean total heterotrophic plate count were 0.00 ± 0.00 cfu/ml in both cases. The detection of E.coli in the water harvested directly from the open space is in agreement with an earlier study by Emerole et al. [27]. However, both the mean total coliform count (97.83 ± 115.03 MPN per 100ml) and the mean total heterotrophic plate count (60.17 ± 94.58) of the galvanized roofs were above the limits. Also, E. coli were not detected in the samples from the harvester while they were detected in the samples from the galvanized roofs.

TABLE 2
BACTERIOLOGICAL ANALYSIS OF WATER SAMPLES FROM THE UMBRELLA AND OTHER TWO SOURCES

Parameter (unit)	Raw rain	Galvanized roofs	Samples from Harvester	WHO standards [25]	SON standards [26]
Total Coliforms (MPN/100ml)	0.33±0.82a	97.83±12.03b	0.00±0.00a	10/100 ml	10/100 ml
Total Heterotrophic plate Count (cfu/ml)	0.00±0.00a	60.17±94.58b	0.00±0.00a	0/100 ml	0/100 ml
E. coli	Absent	Present	Absent	Absent	Absent

Values with different letters (a and b) along the rows are significantly different (p=0.05, n = 4)

3.2 Water Harvesting Potential of the Umbrella and its Cost-Benefit Analysis

The volume of collected water samples at different rainy periods was measured and recorded in order to compare it with the rainfall Fig.s for the same period obtained from the Nigerian Meteorological Agency [28], Oshodi, Lagos. Fig. 4 shows the month-wise harvestable amount of rainwater and the associated amount of cost savings. According to a previous study in Nigeria, the peak rains occur between April and October [15]. In three months of investigation (July, August and September, 2015), the average rainfall data collected using the umbrella were: 18.76 ± 1.16 litres, 13.29 ± 1.11 litres and 22.53 ± 2.07 litres respectively. Within three to four years, the installation cost of a rainwater harvester could easily be recovered with the health status of the user improved.

Water collected in excess of the needs can also be a source of revenue generation. Cost comparison between the umbrella rain harvester and purchasing water from vendors revealed that the umbrella rainwater harvester was cost-effective with associated benefits. This is evident from the results of volume of water collected and cost-benefit analysis of using the umbrella as shown in Fig. 4.

The benefit enjoyed could also be in the form of increased sanitation and water security. In developing countries, it has been reported that informal water vendors tend to use a range of sources – protected and unprotected [29], the umbrella would prevent the outbreak of water-borne diseases as vended water has been associated with outbreaks of diarrhoeal disease [30]. The utilisation of the umbrella would also lead to reduction of the risk of contracting water-related diseases such as typhoid, dysentery, cholera and other diseases that are associated with high morbidity and mortality in Nigerian markets [4].

3.3 Key Informant Interview

In the two markets (Gbagi and Oje) where the Key Informant Interviews were conducted for the market executives, borehole with pumping machine, protected well, uncovered rain water and vended water were identified as key sources of water supply as reported by an informant at Gbagi market, "The sources of water in this market are borehole, well water, sachet water and uncovered rainwater during the rainy season". This agrees with the study on water quality evaluation of hand- dug wells in Ibadan conducted by Ayontobo et al. [31] which revealed that exploitation of groundwater through the construction of hand-dug wells is a major source of water for majority of Ibadan populace. Also, Ajayiet al. [32] reported that in the past several years, globally there has been a wave of sudden awareness among people to switch over from any available water to packaged water for drinking purposes. In a research on the sanitary practices of roadside traders in Nigeria, it was discovered that about 73% of respondents claimed that their water needs were being serviced by water vendors [33, 34] and the quality of the water supplied to them is largely unknown, compromising their health [6]. Generally, all the market leaders agreed that this innovation was viable and reliable, and would greatly improve the sanitation and hygiene conditions in the markets. Consequently, they indicated their readiness to utilise the umbrella.

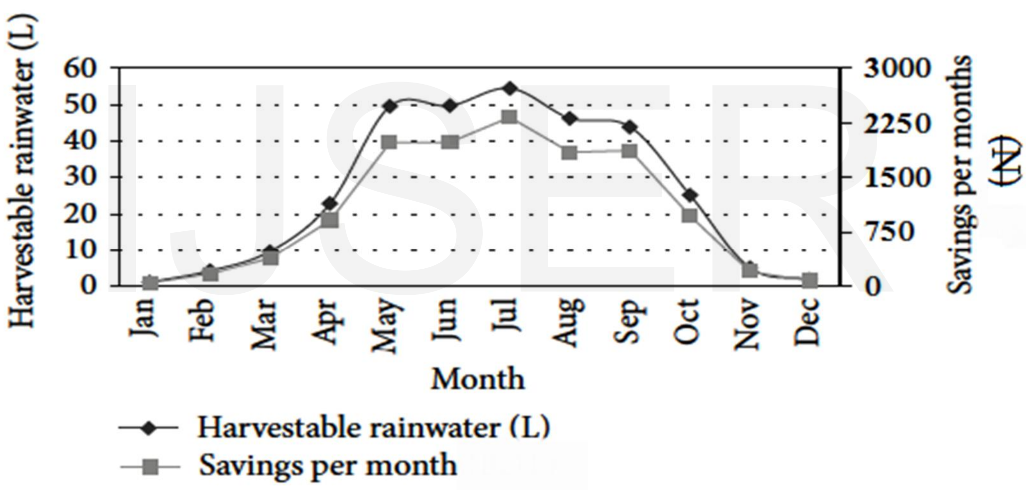

Fig. 4: Monthly harvestable amount of rainwater and the associated cost savings (estimates were made in the year 2015)

4 CONCLUSION

The rain harvester umbrella fabricated locally is very effective as an alternative source of clean and potable water to road side market people in Nigeria. The water harvested by the umbrella is better in terms of physicochemical and bacteriological quality than that collected by galvanized roofs and it had very minimal contamination. However, the quality of water harvested through all the means are within Standard organization of Nigeria and World health organization permissible limits. The benefits associated with the usage of the umbrella rainwater harvester are not only judged in terms of finances that it saves but also in improved hygiene practices and wellbeing of the users. All the market leaders agreed that this innovation was viable and reliable. They believed that the umbrella would greatly improve the sanitation and hygiene conditions of the market environment and they are ready to utilise the umbrella. Utilization of the umbrella may lead to reduction of the risk of contracting water-related diseases such as typhoid, dysentery, cholera and other diseases that are associated with high morbidity and mortality in Nigerian.

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