Research Journal of Engineering and Environmental Sciences 1(1) 2016 pp. 85-97

Research Journal of Engineering and Environmental Sciences

Journal homepage: www.rjees.com

RJEES

Original Research Article

AN OPTIMIZED ARCHITECTURAL INTERVENTION IN ROOFTOP RAINWATER HARVESTING SYSTEM

***Ebhomien, L.E. and Obarisiagbon, O.**

Department of Architecture, Faculty of Environmental Sciences, University of Benin, PMB 1154, Benin City, Nigeria
*ehimen.ebhomien@uniben.edu; osaze.obarisiagbon@uniben.edu

ARTICLE INFORMATION

Article history:
Received 09 November 2016
Revised 02 January 2017
Accepted 05 January 2017
Available online 20 February 2017

Keywords:
Rainwater harvesting system
Architectural intervention
Water management
Architectural optimization
Butterfly roof

ABSTRACT

A survey of urban and rural areas in most part of southern Nigeria reveals 'ad-hoc' integration of auxiliary components to the roof structure of a building for the collection of rainwater through the technology of rainwater harvesting (RWH). Hence, this paper aims to optimize RWH by proposing roof designs capable of enhancing this strategy. The research was conducted by self-administered questionnaire survey in which random sampling was used to obtain views of building users to evaluate the need for an architectural intervention. The data obtained was analyzed, and the results revealed that aesthetic appeal and seasonality of rainfall were the major factors limiting RWH wide spread adoption, while from an architectural perspective, roof optimization was identified. Consequently, concealed roof gutters, optimal rooftop layout configuration, central rainwater collection points, flush diverters, screens and leaf guards were combined in an optimized RWH system implementing butterfly roof and modified inverted umbrella roof as a design solution.

1. INTRODUCTION

It is a common sight in Africa that during the rains, buckets, pots and other vessels are brought under a dripping roof to collect water, and in recent times split sections of pipes or bent corrugated sheets are placed along roof-sides for channeling runoff from the roofs into drums and tanks. This clearly is a water management strategy, and also an indication of the underlying problem of water shortage in the rural and urban areas in Africa (Besada and Werner, 2015). This problem of water scarcity has been attributed to factors such as: population growth, changes in lifestyles due to rapid economic growth (Pandey *et al*., 2003), climate change (Lade and Oloke 2013), over-allocated water systems in urban and non-urban areas (IPCC, 2008) and aging urban water infrastructure (Vlachos and Braga, 2001).

Rainwater harvesting (RWH) technology has been advanced as a veritable water management strategy that can mitigate water problems in both urban and rural centers (Lade and Oloke, 2013). RWH is a technology used for collecting and storing rainwater from rooftops, land surfaces or rock catchments using simple storage utensils, such as pots, tanks, cisterns and more complex options, such as underground check dams (Prinz, 2002; Appan, 1999; Zhu *et al.*, 2004).

In Nigeria, implementation of sustainable water management (SWM) is hampered by social, environmental and technical barriers which currently restrict efficient implementation of water management strategies. This inefficiency contributes to water scarcity, water-borne diseases, ground-water depletion, storm water increase and loss of lives and property (due to flooding) etc. RWH systems have been identified as an important water management strategy which can result in the improvement of the water supply system in Nigeria (Lade and Oloke 2013).

An assessment of buildings in urban and rural areas in most of southern Nigeria reveals the integration of structures such as roof gutters, downspouts, funnels to the roof structure for the collection of rainwater (Onoja et al., 2010; Oni et al., 2008; Lade and Oloke2013). Architecturally these measures could be viewed as improvisations, if architecturally such purpose was not integrated ab initio at the design stage of the roof plan. Therefore given the ubiquitousness of this technology in Nigeria, and the artisanal approach to its development over the years, this study identifies a primary component of a RWH system: the roof; that could be architecturally optimized aesthetically and functionally in order to overcome the social, environmental and technical barrier to the adoption of this technology.

This study is novel, in the sense that it seeks to architecturally enhance the appeal of an existing water management solution, functionally and aesthetically so that its adoption will be widespread. This is in view of the fact that the trend in modern technology is towards sustainability and energy efficient solutions. Hence, this study focuses on the application of architectural expertise for optimizing roof-based RWH for efficient water management. This study is motivated by the need to develop technologies and water management approaches that can be adopted in developing countries like Nigeria, were access to pipe-borne water is inadequate (Adelekan, 2010).

2. METHODOLOGY

2.1. Study Area

The study area comprised of areas within and around the Ugbowo campus of the University of Benin, located in Benin City, Edo state, Nigeria.

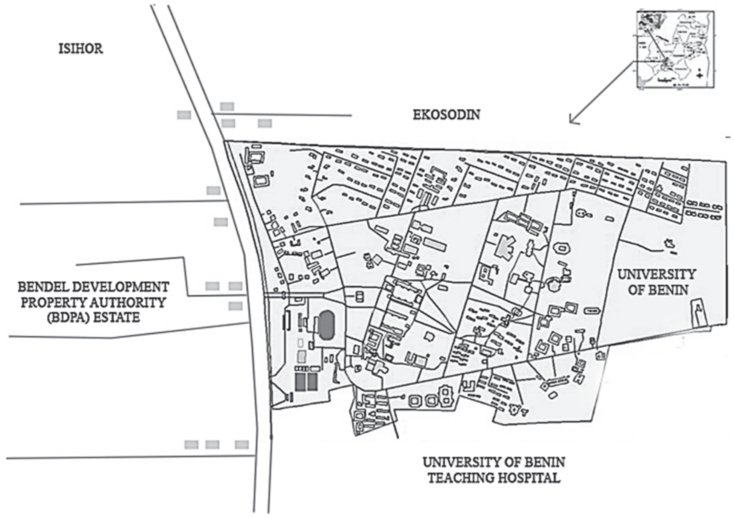

Figure 1: Map of the study area

The study area spans between Longitudes 5°36’24.8”E to 5°37’55.4” E and Latitudes 6°23’33.4’’ N and 6°24’27.3” N respectively and was chosen for the survey because of the prevalence of RWH systems and the demographic distribution of the population which cuts across different educational and socio-economic strata.

2.2. Method of Data Collection

Questionnaires were administered to building users through random sampling in the areas around the Ugbowo campus of the University of Benin. The research questionnaires evaluated the challenges and respondents’ awareness towards RWH. This was done to evaluate the needs required in an architectural intervention. A sample size of randomly selected 27 building users within the University and another 27 within its environs was used for the study which lasted for a period of six weeks.

3. RESULTS AND DISCUSSION

3.1. Analysis of Results

At the end of the survey which lasted for six weeks, 46 questionnaires of the total of 54 administered were returned. This corresponded to a response rate of 85%. The deficit of 15% was recorded because some respondents did not return their questionnaires. The data obtained from the questionnaires was analyzed and the results are presented in the following Figures 2 to 11.

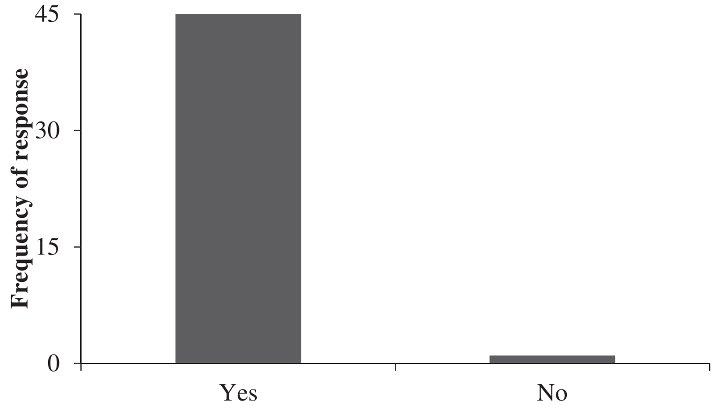

Figure 2: Responses for the question: *"Have you seen an actual rainwater harvesting system before?"*

Figure 2 shows that forty five (45) respondents out the total of 46 (corresponding to 97.83%) indicated that they were aware of what a rainwater harvesting system is, even though majority of respondents didn't own this system in their homes. As indicated in Figure 3, RWH systems are moderately common, implying that it is an acceptable and a commonly adopted solution to water scarcity problem. Figure 4 shows that rainwater is a valuable resource desirable by the majority of the respondents to meet some of their basic needs, but mostly for non-potable uses. Figure 5 shows that most respondents, i.e. 33 (71.74%) of the respondents do not have RWH systems installed in their homes, which when comparatively analyzed with the results presented in Figures 2, 3 and 4 indicates that despite RWH being generally perceived as a water management solution , its installation in homes is low. As shown in Figure 6, a majority of the respondents i.e. 58.7% (27 cases) will not want a RWH system to be installed in their homes or be built into the architectural design of their homes despite the benefits of RWH**,** which highlights the problem of the study: the low level of adoption of a highly beneficial water management strategy that is cheap and sustainable**.** In assessing the barriers to the widespread adoption of RWH systems, the respondents were evaluated on their experience with RWH systems. Figure 7 shows that 63% (29) of the respondents had used a RWH system.

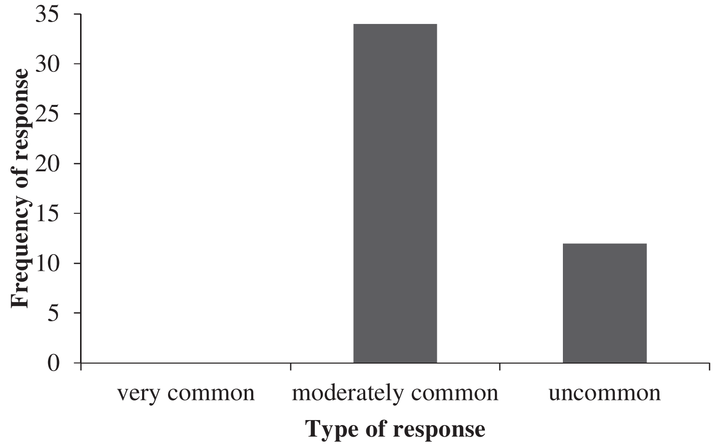

Figure 3: Responses for the question: *"How common do you think rainwater harvesting systems are in buildings in your locality?"*

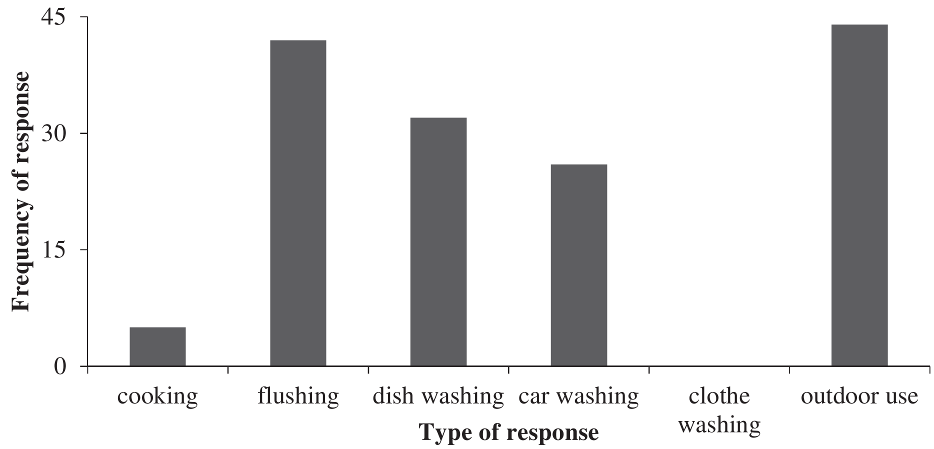

Figure 4: Response for the question: *"Would you consider using rainwater harvested for any of the following uses?*

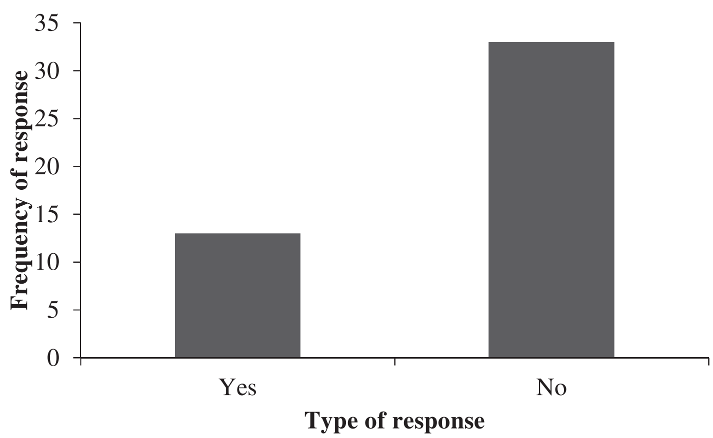

Figure 5: Responses for the question: *"Do you have a rainwater harvesting structure at your residence?"*

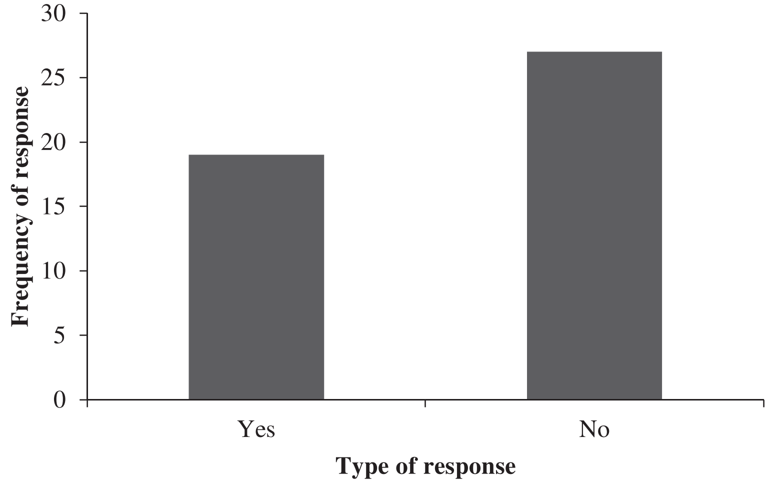

Figure 6: Response for the question*: "Would you like a RWH unit to be built into the architectural design of your house?"*

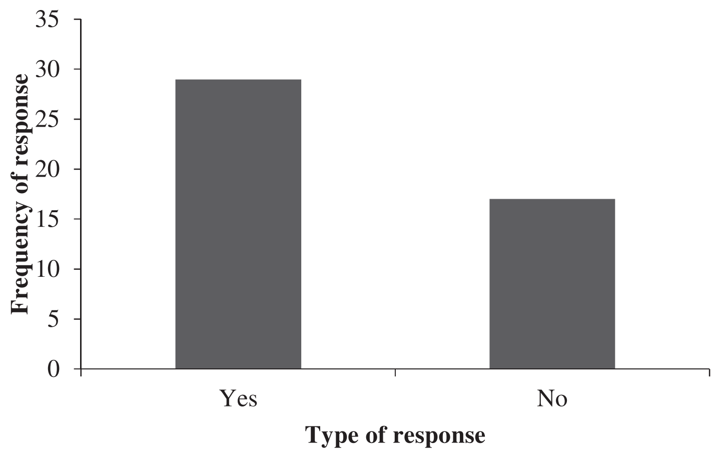

Figure 7: Responses for the question: *"Have you ever used a rainwater harvesting system?"*

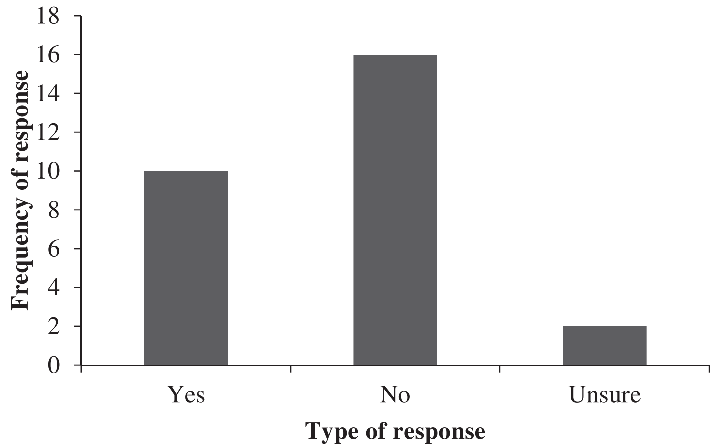

Figure 8: Responses for the question: *"Was the rainwater harvesting system able to meet your needs satisfactorily?"*

As shown in Figure 8, of the 29 respondents, 16 responded that the RWH system did not meet their needs satisfactorily, and attributed the seasonality of the rainwater resource and also the effect of the rooftop, such as rust on the quality of water collected, as problems of RWH. From the results it is also clear that roofing materials affects the perception of RWH technology: as seen in Figure 9. 91% (42) of the respondents reported that they have corrugated metal sheets as roofing materials. This could explain the fact that most of the respondents, who were in the group of those that have used or use RWH systems, mentioned contamination resulting from rust as a major problem with the quality of water collected.

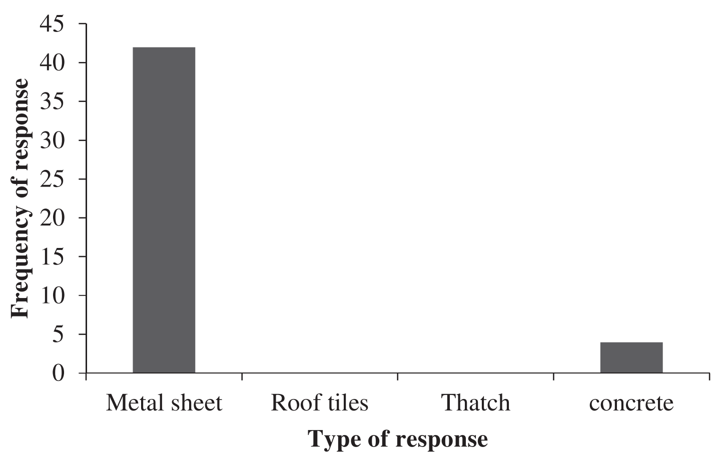

Figure 9: Responses for the question *"What type of material is your roof made of?"*

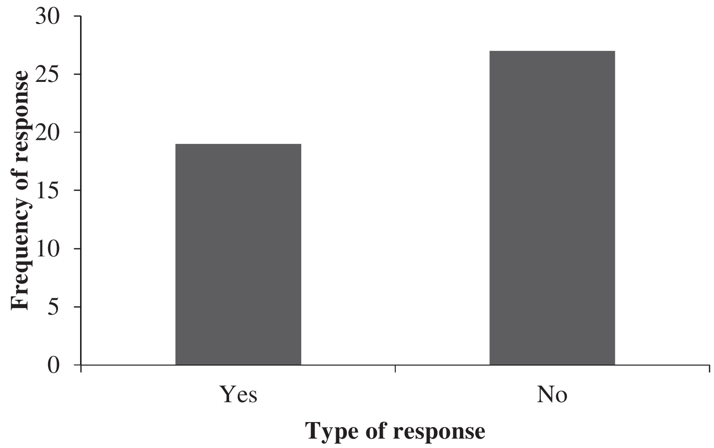

Figure 10: Responses for the question: "*Are the equipment of rainwater harvesting systems aesthetically appealing*?"

It is important to note that these same respondents who do not think that the technology is aesthetically appealing as seen from Figure 10, were also the same respondents who would not integrate a RWH system in the architectural design of their house as shown in Figure 6, thus highlighting a major barrier for the adoption of this technology. This observation is thrown in sharp focus by the response to the question presented in Figure 11, shows that 95.65% of the respondent indicated that they will buy or rent a property with a RWH system. This indicates that though the technology may not be aesthetically appealing and most people may not go out of their way to recommend the facility in their building designs, its functionality as a water management tool is highly appreciated. This suggests that if an external professional input is brought in, such that they see a building whose RWH system is optimal and functional they are likely to purchase it and recommend it in building plans.

From the survey, poor aesthetics and the seasonality of rainwater resource have been identified as the major constraints to RWH adoption. These are different and minimal when compared to the barriers to RWHs in developed countries such as availability of cheap mains water, water lobbies, perceived abundance of water ,reduced summer efficiency due to climate change, health and safety fears, political structures with diverging interests, difficulties with operation/maintenance, lack of interest from water providers, perception as an unproven technology, lack of willingness toward innovation, lack of clearly defined water quality and which is seen as an unconventional approach (Legget et al., 2001; Konig, 2001; Moddemeyer et al., 2003; Hassell, 2005; Brown and Keath, 2008; De Graaf, 2009), which implies that RWH is relatively more acceptable in developing countries, and so should be optimized as a potential solution to shortage of water supply in urban and rural areas.

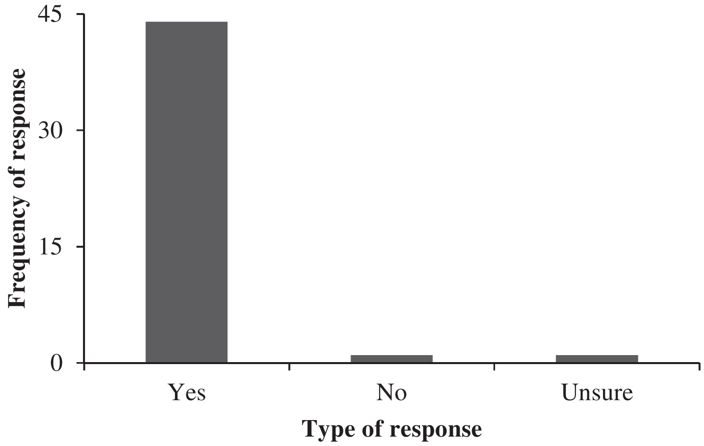

Figure 11: Response to the question: *If a building already has a RWH system will you buy/rent it?*

3.2. Architectural Intervention

From the results of the survey, it was observed that the major factors militating against the wide spread adoption of RWH systems was aesthetic appeal and seasonality of rainwater. On the other hand, from an architectural perspective considering the combined functionality of the roof as a catchment surface and a building envelop, another major factor was roof optimization. Figure 6 and 11, clearly show that respondents were reluctant to integrate RWH systems in homes built by them but would rent or buy an existing building with RWH system. This suggested that though respondent knew RWH was valuable, they did not want to sustain personal losses or bear risk associated with a deficient roof with this combined functionality; hence the goal of the architect is to design a system that satisfies these two functions.

3.3. Recommended Design

In proffering a solution to the identified deficiencies of the roof top RWH system, the following factors were used to determine the most optimized architectural roof design for rainwater harvesting; aesthetics i.e. conspicuousness of the roof gutters and downspout; configuration of roof top layout; and linear length of the periphery of roof where water runs off. Hence the recommended optimal designs are presented in Figure 12 and Figure 13. Figure 12 and 13 are butterfly roof and modified inverted umbrella roof respectively on a simple 2 bedroom flat. The Figures show the catchment area, the conveyance system (i.e. concealed roof gutter, plumbing connections) and the storage system. The design utilises 6 storage tanks installed on a platform 1800 mm high. This was done so that the water harvested can last long and can easily be channelled by the action of gravity into the building for cleaning, washing, bathing, WC flushing, garden irrigation (Jacob et al., 2008). The minimum number of storage tanks was informed by data gathered from this research (Figure 8). This was done to overcome the concerns expressed by the respondents about the seasonality of water. Another solution could be the use of efficient plumbing faucets and fixtures.

L.E. Ebhomien and O. Obarisiagbon / Research Journal of Engineering and Environmental Sciences 1(1) 2016
pp. 85-97

Another problem highlighted was that of rust formation on roofing sheet over time and the transfer of this rust through the rainwater pipes to the tanks. This problem can be addressed by the type of roofing materials used. Aluminium roofing sheets are less prone to rusting; hence are more suitable for RWH system while galvanized (zinc) roofing sheets should be avoided in a RWH system because they corrode easily (Haque et al., 2014). Rainwater harvested from materials such as asphalt, tar shingled roof and stone coated roofs may not be suitable for domestic use because of the leaching of small amount of toxins (Erin, 2014). Installing a first flush diverter component (of 10 to 50 gallons for every 1,000 ft^2 of catchment surface) will enable the first runoff from the roof during rainfall to discharge dust, pollen, leaves, insects, bird faeces and other residue and will serve to wash the roof before subsequent runoff are channelled into storage tank (Erin, 2014). Furthermore, installing screens and leaf guards in roof gutter and downspout will help to prevent debris from cluttering the system.

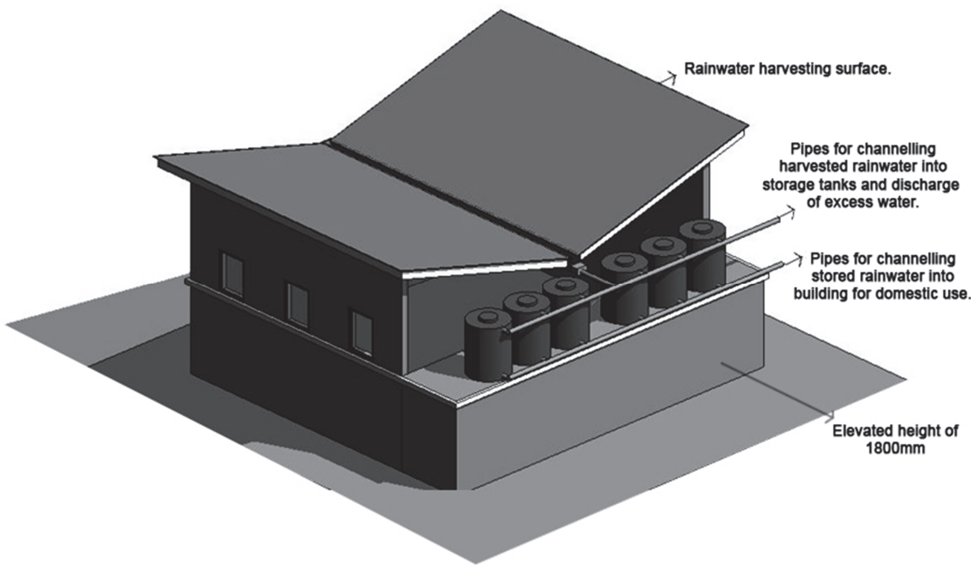

Figure 12: Butterfly roof design

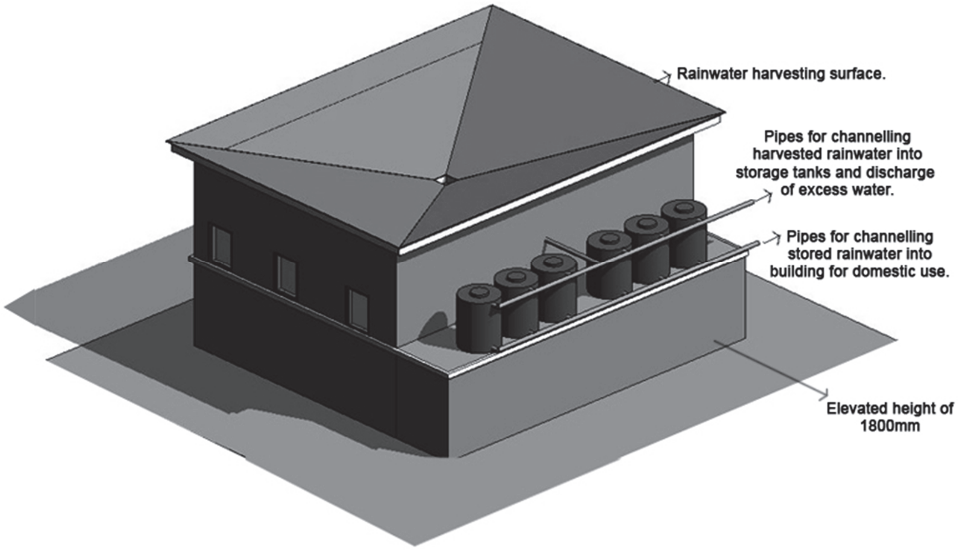

Figure 13: Modified inverted umbrella roof design

To enhance the self-cleansing capacity of the butterfly roof and modified inverted umbrella roof the inclination angle of the roof can be altered to be steeper because steep roof will shed runoff quickly and more easily clean to roof of contamination (Farrency et al., 2011). Runoff coefficient which has a maximum value of 1 is a ratio of runoff harvested to amount of rainfall received on a roof surface. Generally, steep roofs (runoff coefficient > 0.90) with smooth surface will harvest up to 50% more rainwater than flattened roofs (runoff coefficient = 0.62) with rough surface (Farrency et al., 2011).

The design of the butterfly and modified inverted roofs contribute to water security, environmental conservation and ecological sustainability as an enhanced water management strategy capable of meeting the needs of people in urban and rural areas in Africa makes the proposed solution a very viable option.

4. CONCLUSION

This study has highlighted aesthetic appeal, seasonality of rainwater and roof optimization as major barriers to the adoption of RWH technology. It identified the areas in which the architect can intervene in this water management practice. Aesthetics of the design was enhanced through concealed roof gutters, optimal rooftop layout configuration. Through piping and sizing of storage tanks incorporated into building designs, as recommended in this study, the shortages of water occasioned by seasonality of rainwater resource will be mitigated. The roof optimization required for the roof-based RWH was also advanced by designing a central rainwater collection points, using of first flow diverters, screens, leaf guards and suggesting material management principles in implementing butterfly roof and modified inverted umbrella design which utilizes material such as aluminium sheets. It is therefore recommended as findings from this study indicate, that RWH technologists, practitioners, building contractors, real estate developers and government agencies adopt architecturally optimised roof designs to enhance and promote RWH technology, as this proposed solution when integrated into building designs will furnish a more appealing and functional water management system that will contribute to sustainable development in the face of climate change and global warming. Thus this study has made a significant contribution to knowledge in advancing alternative approaches to optimising cheap sustainable water management strategies in third world countries.

5. ACKNOWLEDGMENT

The authors are thankful to their colleagues at the Department of Architecture in the University of Benin, Benin City, Nigeria who provided expertise that greatly assisted this work although they may not agree with all the interpretation provided in this paper. We are also grateful to every questionnaire respondent for their time.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adelekan, B.A. (2010). Water quality of domestic wells in typical African communities: Case studies from Nigeria. *International Journal of Water Resources and Environmental Engineering,* 2(6), pp. 137-147.

Appan, A. (1999). A dual-mode system for harnessing roofwater for non-potable uses. *Urban Water,* 1(4), pp. 317-321.

Besada H. and Werner K (2015). An assessment of the effects of Africa's water crisison food security and management. *International journal of Water resources Development,* 31(1), pp. 120-133.

Brown, R.R. and Keath, N.A. (2008). Drawing on social theory for transitioning to sustainable urban water management: Turning the institutional super-tanker. *Australian Journal of Water Resources,* 12, pp. 73-83.

De Graaf, R. (2009). *Innovations in urban water management to reduce the vulnerability of Cities*. Published PhD thesis, Delft University of Technology. The Netherlands ISBN 9789085595915

Erin, L. (2014). Rainwater Harvesting Systems; *Virginia Cooperative Extension, Virginia Tech, Virginia state University*, Petersburg, Virginia, U.S., https://pubs.ext.vt.edu/BSE/BSE-116/BSE-116-pdf.pdf

Hassell, C. (2005). Rainwater harvesting in the UK–a solution to increasing water shortages. In: *Proceedings of the 9th International Conference on Rainwater Catchment Cistern Systems*. Petrolina, Brazil.

Haque, M.M., Limon, S.A., Moniruzzaman, M. and Bepari, M.M. (2014). Corrosion comparison of galvanized steel and aluminum in aqueous environments. *International Journal of Automotive and Mechanical Engineering*, 9, pp. 1758-1767.

IPCC (2008) In: IPCC (Eds.), *Technical Paper on Climate Change and Water.* IPCC, New York, USA, 244pp.

Konig, K.W. (2001). *The Rainwater Technology Handbook: Rain harvesting in Buildings*. WiloBrian, Dortmund, Germany.

Lade, O. and Oloke, D. (2013) Assessment of rainwater harvesting potential in Ibadan, Nigeria. *Environmental Engineering Research*, 18(2), pp. 1-4.

Oni, S.I., Ege, E., Asenime, C. and Oke, S.A. (2008). Rainwater harvesting potential for domestic water supply in Edo State. *Industrial Journal of Management and Social Sciences*, 2(2), pp. 87-98.

Onoja, S.B., Ocheja I.E., and Isikwe M.O. (2010). *Rainwater harvesting practices and design of rainwater harvesting system for Otukpa Community, Benue State, Nigeria.* CTA Seminar. Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi, Nigeria.

Legget, D.J., Brown, R., Brewer, D., Stanfield, G. and Holliday, E. (2001). *Rainwater and greywater use in buildings: Best practice Guidance.* Construction Industry Research and Information Association (CIRIA) Report C539, London.

Moddemeyer, S., Fleming, P., Lilly, D. and Schimek, G. (2003). Seattle public utilities rainwater harvesting pilot project. In: *Proceedings of the 1st American Rainwater Harvesting Conference, American Rainwater Catchment Systems Association.* Austin, Texas.

Pandey, D.N., Gupta, A.K. and Anderson, D.M. (2003). Rainwater harvesting as an adaptation to climate change. *Current Science,* 85(1), pp. 46-59.

Prinz D (2002). The Role of Water Harvesting in Alleviating Water Scarcity in Arid Areas. In: *Keynote Lecture, Proceedings, International Conference on Water Resources Management in Arid Region.* Vol. 3. Kuwait: Kuwait Institute for Scientific Research, pp. 107–122.

Farrency, R., Morales-Pinzon, T., Guisasola, A., Taya, C., Rieradevall, Y. and Gabarell, X. (2011). Roof selection for rainwater harvesting: Quality and quality assessments in Spain. *Journal of International Water Association, Water Research*, 45(10), pp. 3245–3254.

Jacob, T., Bayer, R., Chery, J., Jourde, H., Le Moigne, N., Boyc, J., Hinderer, J., Luck, B. and Brunet, P. (2008). Absolute gravity monitoring of water storage variation in a karst aquifer on the larzac plateau (Southern France). *Journal of Hydrology,* 359(1–2), pp. 105–117.

Vlachos, E. and Braga, B. (2001) The challenge of urban water management In: C. Maksimovic and J. A. Tejada-Guibert (Eds.), *Frontiers in Urban Water Management: Deadlock or Hope*. London, UK. IWA Publishing, pp. 1-36.

Zhu, K., Zhang, L., Hart, W., Liu, M. and Chen, H. (2004) Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of Northern China. *Journal of Arid Environments*, 57, pp. 487-507.