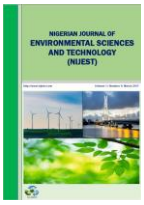
Nigerian Journal of Environmental Sciences and Technology (NIJEST)

www.nijest.com

ISSN (Print): 2616-051X | ISSN (electronic): 2616-0501

Vol 2, No. 2 October 2018, pp 266 - 274



Rainwater Harvesting System for Water Supply in a Rural Community in Edo State, Nigeria

Okovido J. O.[1,*], Owen-Egharevba U.[2] and Akhigbe L. O.[3]

[1,2,3]Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria

Corresponding Author: *johnokovido@rocketmail.com

ABSTRACT

Water scarcity is still a major problem in many rural communities in Nigeria. In this study, a rain water harvesting system was designed for Ogbekpen, a rural community in Edo state, Nigeria. A conceptual model for rainwater harvesting was developed using the storm water management model (SWMM), Arcmap 10.1 software and daily rainfall data (2000-2016) obtained from the Nigerian Meteorological Agency (NIMET). Runoff, rainfall intensity and change in elevation of three designated catchment zones were taken into consideration. The results revealed that the total amount of rainwater that could be harvested annually (water supply) was 14,314,351.70 L (14,314 m^3) from an overall effective rooftop area of 6025.9 m^2. This was three times the annual water demand (4,317,965.60 L (4318 m^3)), thus demonstrating the capability of the system to meet annual water demand. The required tank capacities for zones 1, 2 and 3 were 870,412.76 L (870 m^3), 955,319.4 5L (955 m^3) and 788,629.88 L (789 m^3) respectively. Comparative physicochemical and microbial analysis of water from rooftops in the three zones and an existing storage well showed that the latter did not comply with drinking water quality guidelines, thus highlighting the importance of a proper conveyance and storage system to improve water quality and availability in the area.

Keywords: Rainwater harvesting, Water supply, Water demand, Storm Water Management Model (SWMM), Rural community

1.0. Introduction

Rainwater harvesting (RWH) primarily involves the collection, storage and subsequent use of captured rainwater. This is usually known to serve as the principal or supplementary source of water and is applicable for both potable and non-potable uses (Fewkes, 2006)**.** Notably, RWH in developed countries mainly serves to compliment conventional non-potable uses such as clothes washing, toilet flushing, irrigation, and outdoor washings (Hermann and Schmida, 1999; De Gouvello *et al*., 2005; Schets *et al*., 2010; Golay, 2011). In most developing countries however, it provides means to cope with water shortages for both potable and non-potable use (Meera and Ahammed, 2006). In Nigeria, many rural communities still suffer the burden of having to trek long distances in search of water for daily domestic use, thereby wasting time meant for other productive ventures. However, where some form of water sources are available; its quality remains questionable with potential health risks. The quality of rainwater is directly related to the atmosphere as well as quality of materials used for catchment surfaces, gutters and storage tanks (Ariyananda, 1999). Conversely, in areas where the roof top is clean, impervious and made from nontoxic materials, rainwater is usually of good quality and does not require much treatment before consumption (Lekwot *et al*., 2012).

There have been some published studies on rainwater harvesting in Nigeria (Tobin *et al*., 2013; Lade and Oloke, 2015; Shittu *et al*., 2015; Abenu *et al*., 2017). In a study assessing rain water harvesting systems in a rural community in Edo State, it was observed that rainwater harvesting, though widely practiced, was done using poorly designed and maintained systems, resulting in unacceptable levels of microbial contamination (Tobin *et al*., 2013). Abenu *et al.* (2017) investigated rainwater harvesting as a strategy adopted by the inhabitants of Lokoja town, to meet domestic water needs, and reported that rainwater harvesting was adopted by more households in unplanned neighborhoods than planned neighborhoods.

The aim of this study was to design a rainwater harvesting system for Ogbekpen community, Nigeria using the storm water management model (SWMM) for efficient collection and storage of potable water to meet annual demand.

2.0. Methodology

2.1. Description of study area

Ogbekpen, a rural community in Ikpoba-Okha Local Government Area, Edo State, is located at 6° 8'52.52"N Latitude and 5°33'47.03"E Longitude and is 21 m above mean sea level. It has a tropical climate and receives high rainfall during the raining season, with severe water scarcity in the dry season (Ogwu *et al.*, 2014). Inhabitants of the growing Agrarian community are low income earners and have a major need to access water for domestic use. However, water collection in the community has remained burdensome. A Satellite image of the study area is presented in Figure 1.

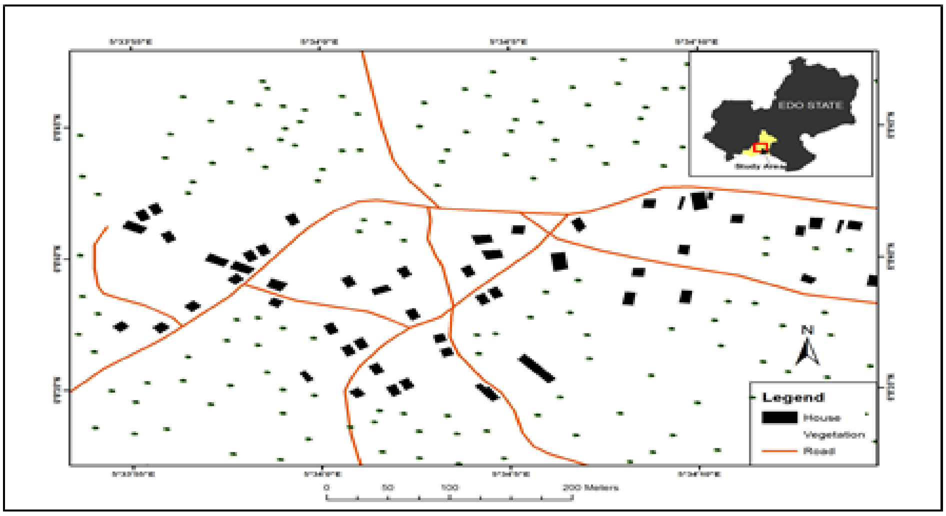


Figure 1: Satellite image of study area
(Source: Google Earth)

2.2. Meteorological data and rainfall analysis

Daily rainfall data for the period of 2000 to 2016 was obtained from the Nigerian Meteorological Agency (NIMET). The daily data was used to calculate the mean monthly and annual rainfall for the study area.

2.3. Delineation of catchment area

To determine the catchment zones that will contribute to rainwater harvesting in the study area, three zones were delineated, taking into cognizance their elevations. Storage units for harvested rainfall water were located at lower elevation zones for easy collection. Slopes were developed using Arcmap 10.1 contour tool. A Digital Elevation Model (DEM) of 30 m resolution was processed to generate a Triangulated Irregular Network (TIN) of the study area.

2.4. Routing of rainwater

This was carried out using kinematic wave method which is a hydrological modeling method. The kinematic wave model equation is developed from the continuity equation for unsteady channel flow with lateral inflow and Manning's equation (Eagleson, 1970).

2.4.1. Area contributing to runoff

The rooftop areas were digitized using Arcmap 10.1 to establish the area of contributing rooftop. Rooftops were considered based on clustering, to allow for ease of networking. Using the geometric calculation tool in Arcmap 10.1 the area of digitized rooftops was calculated.

2.4.2. Demand and supply of harvested rainwater

The monthly water consumption for the study area was computed using a per capita demand of 40 litres per person per day, given the population estimate of 215 (Federal Republic of Nigeria, 1991).

2.4.3. Estimation of storage tank capacity, sizing gutters and downspouts

Three storage tank locations were selected in the entire study area. To calculate the size of storage tank for each zone, the largest harvest of rainwater for each month was considered. As a safety factor, the tank was proposed with an increase of 20% of the required size (UN-HABITAT, 2005). The size of the rooftop gutters and conveyance pipes was then calculated. The gutter was designed using a minimum slope of ≤ 6.25% to allow easy flow of water along the gutter (Despins, 2010). The burial depth of conveyance pipe was then determined using the following equation:

$$D_i = D_f - L_p S_p + L_g S_g \tag{1}$$

where:

- D_i Initial pipe burial depth in m
- D_f Final pipe burial depth in m
- L_p Length of pipe in m
- L_g Length of pipe for which there is grade change in m
- S_p Pipe slope factor (0.01 recommended)
- S_g Grade slope factor (assumes downward slope)

2.4.4. Modeling and design of rainwater harvest system

The Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) software was used to model and design the rainwater harvesting system. This was done by considering the runoff, rainfall intensity and change in elevation in various catchment zones. The model was used to establish the length and size of pipes and location of storage points based on some hydrological parameters. In carrying out the actual rainwater modeling, rainfall intensity for 5 mins interval was sourced from the National Center for Energy and Environment, University of Benin. The rainfall event selected was for the month of September and was recorded for 1 hr 45 mins. The rainfall intensity data and the design hyetograph were then obtained, respectively. Simulation was carried out using the model parameters.

2.5. Storage of harvested rainwater

The storage tank size was considered using a Supply Side Approach (SSA). This method takes into consideration the uneven distribution pattern of rainfall. As in the case of the study area, where there is high rainfall in the months of April-October.

The size of the storage tanks was calculated using the following formula:

$$\text{Size of storage tank} = R_a \times A_r \times R_c \tag{2}$$

where:

- R_a Catchment area in m^2
- A_r Average annual rainfall in mm
- R_c Runoff coefficient

2.6. Water quality analysis

Rainwater samples were collected in pre-rinsed plastic bottles from rooftops in each delineated zone and an existing storage well. Samples were analyzed in accordance with standard methods (APHA, 2001). Heavy metals were analyzed using a Perkin Elmer model 302 atomic adsorption spectrophotometer (AAS). The "HiSelective" *Escherichia coli* (*E.coli*) test kit was used to test for total and fecal coliforms.

3.0. Results and Discussion

3.1. Reconnaissance survey of RWH in Ogbekpen

A survey of current rainwater harvesting practices in the study area was conducted. It was observed that there is no organized system for rainwater collection. The existing conveyance structures were poorly constructed and the collected rainwater was exposed to pollutants, as the storage facilities were barely covered. Figure 2 shows a typical rainwater harvesting system in the area. However, this unconventional practice of rainwater harvesting, though a palliative of some sort, is not affordable for a number of households in the area.

Figure 2: Existing household rainwater harvesting practices in Ogbekpen community

3.2. Meteorological data and rainfall analysis

The chart of normal rainfall and monthly rainfall average presented in Figure 3 shows the month of March-October to be with consistent rainfall, with the highest monthly rainfall in April. The distribution of rainfall shows high potentials for rainwater harvesting in Ogbekpen as 8 months of the year are seen to have abundant rainfall.

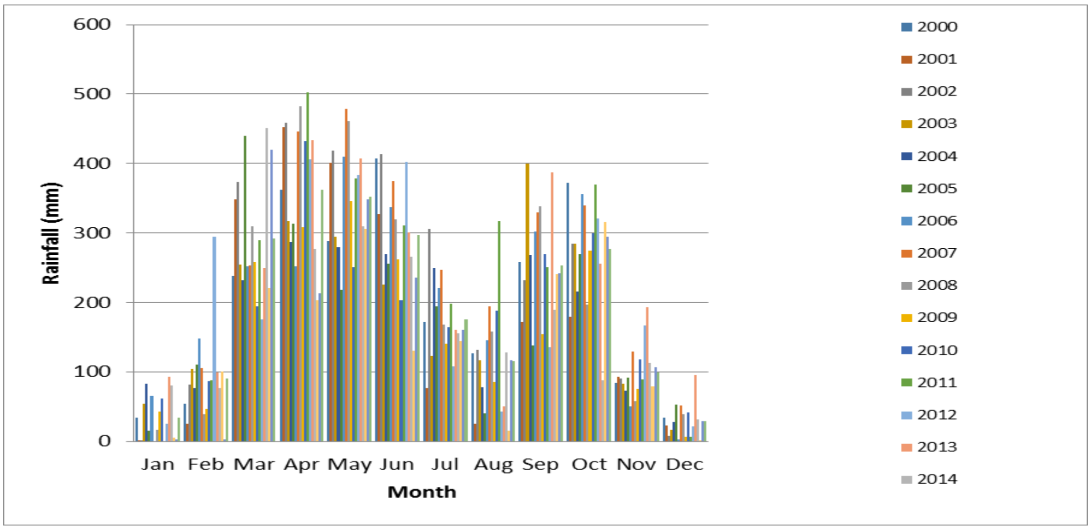


Figure 3: Normal and monthly rainfall average of Benin City from 2000- 2014

3.3. Delineation of catchment area

A Digital elevation model of 30m resolution was processed to generate a Triangulated Irregular Network (TIN) of the study area as shown in Figure 4. The map was used to delineate the study area into three zones based on elevation characteristics. The contour map of the study area shows that the highest elevation is 36m and lowest elevation is 11m, with a gentle sloping terrain (5-8°). Storage units for harvested rainwater were located at lower elevation regions of each zone. The elevation and slope angles contribute to the hydrological parameters required for modelling and are important in the selection of flow direction in each water distribution pipe, as relevant gradient is required for the free flow of harvested rainwater to storage points.

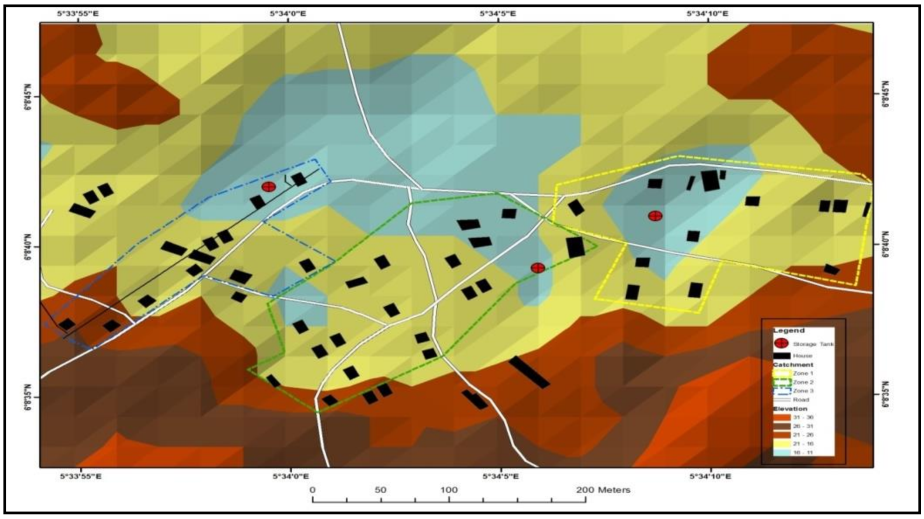


Figure 4: Elevation map using a triangulated irregular network (TIN)

3.4. Demand and supply of harvested rainwater

The water demand and supply for each zone was calculated using the catchment area of each zone and the average monthly rainfall. The rooftop areas were digitized using Arcmap 10.1 and calculated using the geometric calculation tool. Zone 2 had the highest catchment area with an area size of 2,201.9 m^2; zone 1 has an area size of 2006.2 m^2, while the least size is zone 3 with an area of 1817.7 m^2, giving a total effective rooftop area of 6025.9 m^2. Table 1 shows a breakdown of water demand and supply for each catchment zone. The highest amount of harvested rainwater was recorded in the month of April, with a mean value of 2,178,635.08 L (2179 m^3).

The monthly rainwater supply, demand and balance are presented in Table 2. It can be observed that for the month of January and December there was a deficit in water supply due to decreased rainfall. However, the total annual rainwater supply, 14,314,351.70 L (14,314 m^3) is more than three times the amount of water required annually 788,629.88 L (789 m^3), resulting in a water balance of 11,166,751.70 L (11,167 m^3). This indicates that the RWH system will meet and even exceed annual demand with an efficient harvesting and storage system.

Table 1: Harvested rainfall for each zone

Month	Average Rainfall (2000 - 2016) (mm)	Rainfall harvested in Zone 1(L)	Rainfall harvested in Zone 2 (L)	Rainfall harvested in Zone 3 (L)	Total Supply (L)
Jan	34.04	68,287.51	74,948.79	61,871.30	205,107.60
Feb	90.39	181,330.98	199,019.38	164,293.35	544,643.71
Mar	291.65	585,104.69	642,180.25	530,129.00	1,757,413.94
Apr	361.55	725,343.97	796,099.54	657,191.57	2,178,635.08
May	351.66	705,495.57	774,314.97	639,208.11	2,119,018.65
Jun	296.39	594,622.34	652,626.32	538,752.38	1,786,001.04
Jul	175.73	352,548.35	386,938.59	319,423.35	1,058,910.29
Aug	115.15	231,006.85	253,541.01	209,301.74	693,849.60
Sep	253.47	508,506.79	558,110.41	460,728.14	1,527,345.35
Oct	277.29	556,294.48	610,559.67	504,025.76	1,670,879.90
Nov	99.5	199,611.00	219,082.57	180,855.80	599,549.38
Dec	28.71	57,596.82	63,215.25	52,185.10	172,997.17
Total	2,375.51	*4,765,749.34*	*5,230,636.76*	*4,317,965.60*	14,314,351.70

** Runoff coefficient = 0.9*

Table 2: Harvested rainwater supply and demand balance

Months	Number of Days	Monthly Supply (L)	*Monthly Demand (L)	Monthly Balance (L)
January	31	205,107.60	266,600.00	-61,492.40
February	29	544,643.71	249,400.00	295,243.71
March	31	1,757,413.94	266,600.00	1,490,813.94
April	30	2,178,635.08	258,000.00	1,920,635.08
May	31	2,119,018.65	266,600.00	1,852,418.65
June	30	1,786,001.04	258,000.00	1,528,001.04
July	31	1,058,910.29	266,600.00	792,310.29
August	31	693,849.60	266,600.00	427,249.60
September	30	1,527,345.35	258,000.00	1,269,345.35
October	31	1,670,879.90	266,600.00	1,404,279.90
November	30	599,549.38	258,000.00	341,549.38
December	31	172,997.17	266,600.00	-93,602.83
Total		14,314,351.70	3,147,600.00	11,166,751.70

**40 liters per person, for 215 persons*

3.6. Estimation of storage tank capacity

The tank capacity for each zone was calculated as presented in Table 3. The required tank capacities for zones 1, 2 and 3 were 870,412.76 L (870 m^3), 955,319.45 L (955 m^3) and 788,629.88 L (789 m^3) respectively. This invariably means the largest tank would be allocated to zone 2.

Table 3: Maximum harvested rainwater and storage tank sizing

	Zone 1	Zone 2	Zone 3
Maximum Harvested Rainfall (L)	725,343.97	796,099.54	657,191.57
Storage Tank Size (with 20% safety factor) (L)	870,412.76	955,319.45	788,629.88

3.7. Modeling and design of rainwater harvest system

A layout of the conveyance model for each catchment zone is presented in Figure 5. S_1, S_2 and S_3 are the projected storage tank locations for zone 1, 2 and 3 respectively. The water elevation profile (Figure 6) shows the gradient of each conduit considering the slope angles. The steepness of the profile is important to allow for flow of water to storage location.

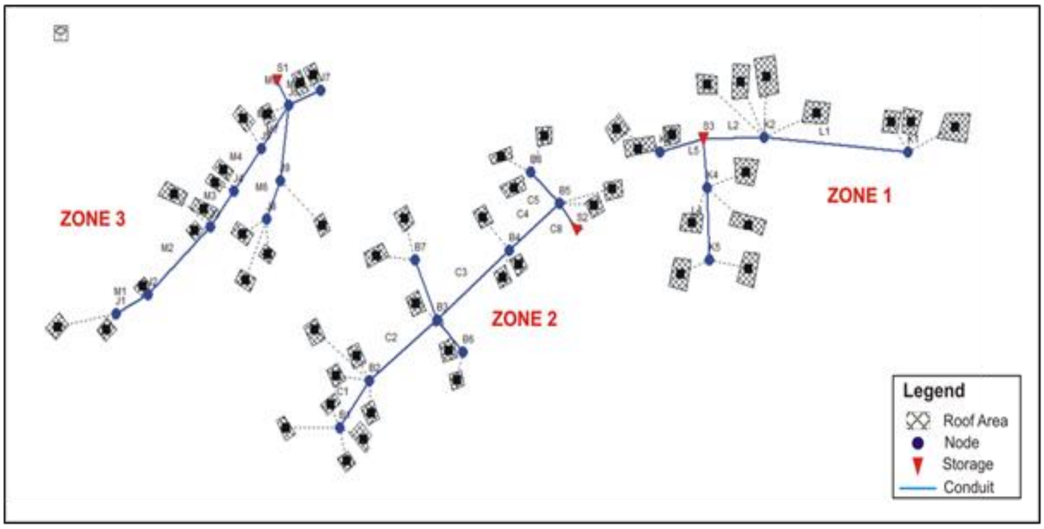


Figure 5: Conveyance system for rainwater harvesting

Data obtained after simulation and proper pipe sizing showed that the average pipe size required was 0.3 m and pipe lengths ranged from 16 to 79 m.

The outlet hydrographs obtained for each of the catchment zones is presented in Figure 7. From the graph the peak inflows were 0.089, 0.12 and 0.15 m^3/s in zones 1, 2 and 3 respectively. The time duration peak inflow coincides with the peak precipitation time in the graph. This shows a direct relationship between precipitation and inflow. The total infiltration was 2.9% of the total precipitation, as the catchment area had a runoff coefficient of 0.95.

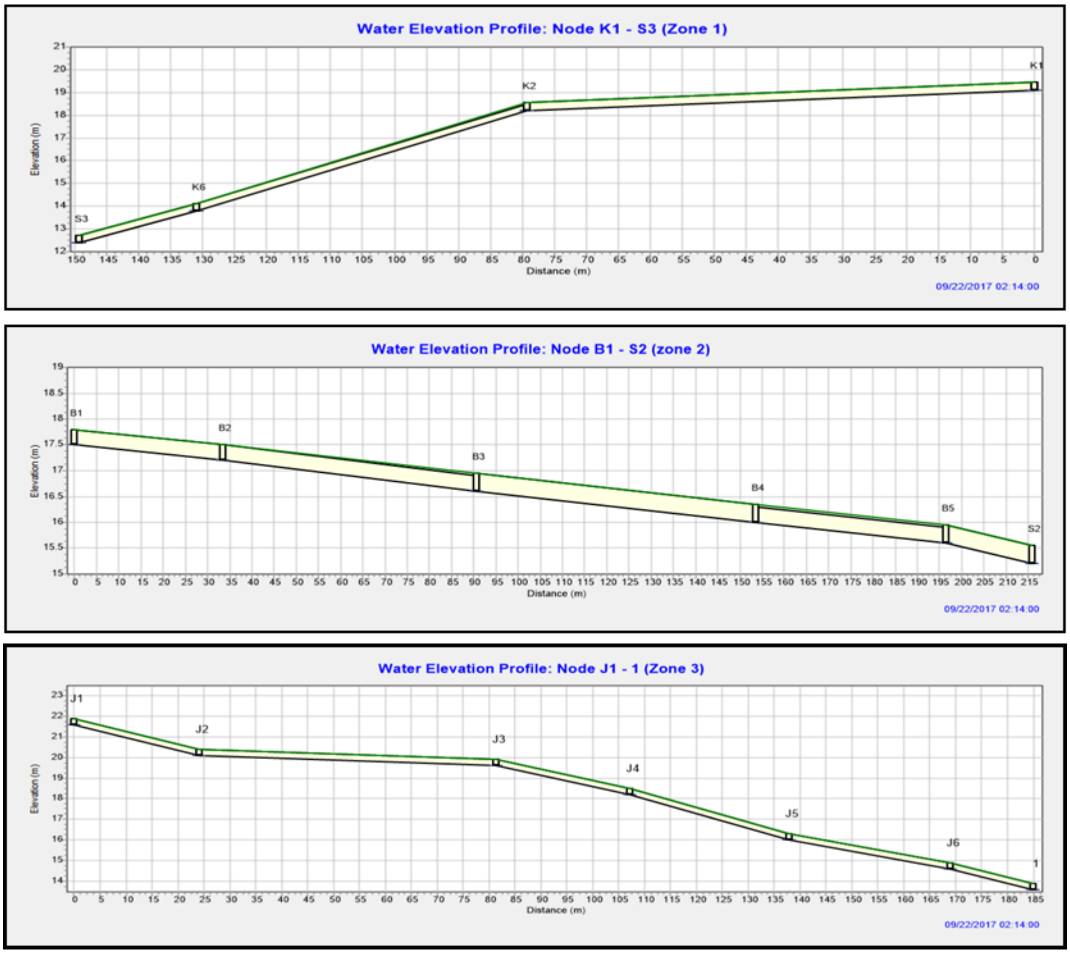


Figure 6: Water elevation and conduit profiles

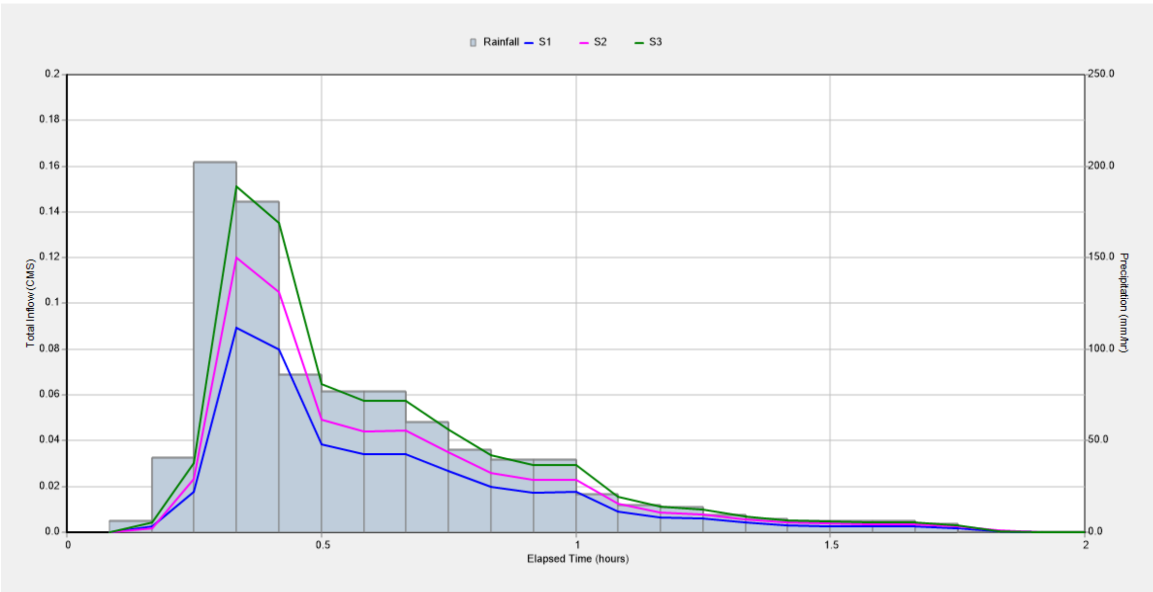


Figure 7: Inflow hydrograph

3.8. Water quality analysis

Physicochemical and microbial analysis of water samples showed that water from the rooftops (zones 1-3) met World Health Organization (WHO) standards for drinking water (Table 4), except for the Total Suspended Solids (TSS). However, the pH, Total Suspended Solids (TSS) and fecal coliform count in water from the existing well did not comply with the WHO standards. This can be attributed to the poor conveyance structure and maintenance of the existing wells and highlights the need for disinfection (chlorination) to make the water safe for human consumption.

Table 4: Physicochemical and microbial characteristics of rainwater samples

Parameters	Zone 1	Zone 2	Zone 3	Existing Well	WHO (2011)
pH	6.6	6.7	6.5	5.9	7.5
TSS (in mg/L)	1.5	2.8	1.6	20.6	0
TDS (in mg/L)	37.1	35.7	36.2	103.1	500
Na (in mg/L)	0.5	0.61	0.57	2.45	200
K (in mg/L)	0.12	0.19	0.17	1.2	500
Ca (in mg/L)	1.56	1.8	1.66	12.8	200
Mg (in mg/L)	0.77	0.79	0.76	2.3	50
Cl (in mg/L)	16.87	17.7	17.5	32.3	250
Fe (in mg/L)	0.06	0.13	0.15	0.18	0.2
Mn (in mg/L)	0.012	0.008	0.013	0.018	0.05
Zn (in mg/L)	0.06	0.1	0.13	0.16	3
Fecal Coliforms (/100ml)	ND	ND	ND	5	0

4.0. Conclusion

In this study, a rain water harvesting system was designed for Ogbekpen, a rural community in Edo state, Nigeria. The storm water management model (SWMM) and Arcmap 10.1 software were used to develop a conceptual model for rainwater harvesting with daily rainfall data (2000-2016) obtained from the national meteorological agency (NIMET). The results revealed that the total annual amount of rainwater (water supply) was 14,314,351.70 L (m3) from an overall effective rooftop area of 6025.9 m^2. This was three times the annual water demand (4,317,965.60 L), thus demonstrating the capability of the system to meet annual water demand. The required tank capacities for zones 1, 2 and 3 were 870,412.76 L (870 m^3), 955,319.45 L (955 m^3) and 788,629.88 L (789 m^3) respectively and the average pipe size was 0.3 m. Physicochemical and microbial analysis of water samples showed that water from the rooftops (zones 1-3) met WHO standards for drinking water, except for the TSS, while the pH and fecal coliform count in water from the existing well did not comply with WHO standards. The findings of this study have demonstrated the potential capability of a well-designed rainwater harvesting system to meet annual water demand in a rural community, thus improving the quality of life.

References

Abenu, A., Abah, O.L., Ibrahim, Y.B. and Nasiru, I.M. (2017). Assessment of rainwater harvesting as a strategy by households in Lokoja town, Kogi state. *Proceedings of the 8th International Conference; Hydrology and water resources development*, pp. 112-115.

APHA (2001).*Standard methods for the examination of water and wastewater.*20th Edition, American Public Health Association, Washington DC.

Ariyananda, T. (1999). Comparative review of drinking water quality from different rainwater harvesting systems in Sri Lanka. *Proceedings of the 9th International rainwater catchment systems conference 'Rainwater catchment: An answer to the water scarcity of the next millennium,* Petrolina, Brazil.

De Gouvello, B., Derrien, F. and Khouil, Y. (2005). The French experience in rainwater reuse in commercial buildings. *Plumbing System Design,* pp. 12-17.

Despins, C. (2010). *Alberta Guidelines for Residential Rainwater Harvesting Systems*, Alberta, Canada.

Eagleson, P.S. (1970). *Dynamic Hydrology,* 1st Edition, McGraw-Hill, New York.

Federal Republic of Nigeria, (1991).*The Nigeria Population Commission (NPC) official result for house and population census figures.* Bureau for National Statistics, Abuja.

Fewkes, A. (2006).The technology, design and utility of rainwater catchment systems. In: *Water demand management*, edited by Butler, D. and Memon, F.A. IWA Publishing, London.

Golay, F. (2011). *Rainwater harvesting in urban New Zealand [M.Sc. thesis]*, Ecole Polytechnique Federale de Lausanne/Massey University, Lausanne, Switzerland.

Hermann, T. and Schmida, U. (1999). Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water*, 1(4), pp. 307-316.

Lade O. and Oloke, D. (2015). Rainwater harvesting in Ibadan city, Nigeria: Socioeconomic survey and common water supply practices. *American Journal of Water Resources*, 3(3), pp. 61-72.

Lekwot, V.E., Ikomomi, S., Ifeanyi, E. and Onyemelukwe, O. (2012). Evaluating the potential of rainwater harvesting as a supplementary source of water supply in Kanai (Mali) district of Zangon-kataf local government area of Kaduna state, Nigeria. *Global Advanced Research Journal of Environmental Science and Toxicology*, 1(3), pp. 38-45.

Meera, V. and Ahammed, M.M. (2006).Water quality of rooftop rainwater harvesting systems: a review. *Journal of Water Supply: Research and Technology-Aqua*, 55(4), pp. 257-268.

Ogwu, M.C., Osawaru, M.E. and Chime, A.O. (2014). Comparative assessment of plant diversity and utilization patterns of tropical home gardens in Edo State, Nigeria. *Scientia Africana*, 13(2), pp. 146-162.

Shittu, O.I., Okareh, O.T. and Coker, A.O. (2015). Development of rainwater harvesting technology for securing domestic water supply in Ibadan, Nigeria. *International Research Journal of Engineering Science, Technology and Innovation*, 4(1), pp. 32-37.

Schets, F.M., Italiaander, R., Van den Berg, H. and de RodaHusman, A.M. (2010). Rainwater harvesting: quality assessment and utilization in the Netherlands. *Journal of Water Health*, 8(2), pp. 224-235.

Tobin, E.A., Ediagbonya, T.F., Ehidiamen, G. and Asogun, D.A., (2013).Assessment of rain water harvesting systems in a rural community of Edo State, Nigeria. *Journal of Public Health and Epidemiology*, 5(12), pp. 479-487.

UN-HABITAT (2005). *Rainwater Harvesting and Utilization. BlueDrops Series*, United Nations Habitat Programme, Nairobi, Kenya.

WHO (2011). *Guidelines for Drinking-water Quality*, 4th Edition, World Health Organization, Geneva, Switzerland.