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Preliminary Assessment of Rainwater Harvesting Potential in Nigeria: Focus on Flood Mitigation and Domestic Water Supply

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Abstract This study was accomplished using 26 locations in the major ecological zones of Nigeria as well as different classes of residential buildings and different levels of water consumption. For each location, house dwelling class and level of water consumption, a water balance approach was used to assess the proportion of water demand that can be met by rainwater. Results obtained indicate that for all the locations in the rainforest zone and some parts in the guinea savanna zone, over eighty percent (80 %) of water demand of those living in bungalows can be met by rainwater. Rainwater harvesting potential was found to be a power function of rainfall coefficient of variation, with coefficient α and exponent β. High correlation coefficients ($0.881 \leq R^2 \leq 1$) were obtained between coefficient α and roof area per capita. Also, high correlation coefficients ($0.847 \leq R^2 \leq 0.992$) were obtained between exponent β and roof area per capita.

Keywords Rain · Water · Rainwater harvesting · Water balance · Coefficient of variation

1 Introduction

This paper strongly advocates the use of rainwater as the major source of domestic water supply, especially in areas where public supply has failed; and as a flood mitigation measure. Al-Salim (2011) stated that rainwater appears to be one of the most promising alternatives for supplying water in the face of increasing water scarcity and escalating demand. Corroborating this view, Deri et al. (2012) observed that, captured and stored correctly, rainwater is a safe, economical and sustainable source of quality water. Chukwuma et al. (2012) defined rainwater harvesting as a simple, low cost water supply technique that involves the capturing and storing of rainwater from roof top and ground catchment for domestic, agricultural, industrial and environmental purposes. Aladenola and Adeboye (2010) noted that rainwater harvested and stored in the rainy season can supplement for water demand in the dry season. Rainwater can be used for non potable purposes such as irrigation, car washing, toilet flushing; and potable purposes such as drinking, cooking and bathing if subjected to some level of treatment or even

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without treatment (Tripathy and Pandey 2005; Lekwot et al. 2012). However, there is need for supplementation of fluoride in rainwater designated for domestic uses, since this essential compound is absent in rainwater (Sazakly et al. 2007). However, the general attitude of urban dwellers in Nigeria towards rainwater is that it is unsafe and for the poor. The rich usually consider it, beneath their status to harvest rainwater because of their ignorance of improved rainwater harvesting technologies. People are more inclined to opt for a borehole or dug well instead of installing rainwater harvesting technologies. A survey conducted in Northern Nigeria by Ishiaku et al. (2012) showed that only 3 % of sampled population harvested rainwater. Just like every other source of water, rainwater contains some levels of impurities resulting from its contact with dust particles and gaseous oxides in air; dust, debris, leaves and bird droppings on roof tops; sewage, organic and inorganic minerals on ground surface; and other obstacles such as trees, electric and telecommunication masts, etc. Other contaminants found in harvested rainwater are pathogenic bacteria, heavy metals, ashes, mosquito larvae, industrial emissions, roof materials and dirt from storage facilities (Mosley 2005). For domestic purpose, rainwater should be collected from roof tops as water from the roof top is usually less polluted than that collected over the ground surface (Eruola et al. 2012). Elleta and Oyeyipo (2008) observed that harvested rainwater is also dependent on the type and age of collection surface. They found high levels of iron and zinc in rainwater collected over aged roofs. Hence, galvanized steel and aluminum roof are recommended for rainwater collection, since aluminum is fairly inert and galvanization protects roofs from corrosion (Mosley 2005). The quality of harvested rainwater also increases with time from the onset of rainfall. Analyses of rainwater collected from a tile and a galvanized iron roofs showed that the concentrations of various pollutants were high in the few litres, but decreased in subsequent samples (Yaziz et al. 1989).

Harvesting of rainwater in a particular region is highly dependent upon the amount of and intensity of rainfall and some other factors like catchment area and type of catchment (Deri et al. 2012). Dillaha and Zolan (1985) observed that catchment characteristics had significant effect on total coliform bacteria levels of harvested rainwater. Rainfall distribution and variation in Nigeria have been captured by the major ecological zones which include the rainforest zone, the derived guinea savanna, the southern guinea savanna, the northern guinea savanna, the arid and the semi arid zones. Rainfall increases in magnitude from the arid zone in the North West to the rainforest zone in the South South. The rainforest and parts of the derived guinea savanna zones are characterized by high rainfall intensity, long wet season, dense vegetation, rugged topography and temperature range of 26–28 °C. Conversely, northern and southern guinea savanna, the arid/semi arid zone and other parts of the derived guinea savanna are located in the northern part of the country and are characterized by short wet season and long dry season, high annual temperature (average) of the range 28–32 °C. The montane forest/grassland zone is located in the high altitude areas of the country and is known for low average annual temperature (20–23 °C) all year round, moderately high rainfall and rugged topography (Sowunmi and Akintola 2010). The arid/semi arid zone is the driest part of the country. Rainfall varies from 1,500 mm per annum in the southern part to 400 mm in the northern part. The rainy season lasts from about 7 months (April to October) in the southern part to as low as 3 months (July to September) in the northern part (Ati et al. 2009). It is therefore the aim of this study to make a preliminary assessment of rainwater harvesting potentials of the ecological zones. In this study, it is our intention to show that rainwater can serve as the main source of domestic water supply while other sources can serve as supplementary for deficit. This study also intends to show that rainwater harvesting can serve as a simple, low cost and effective means of combating urban flooding resulting from escalating volume of runoff.

2 Methodology

This study sought to determine the proportion of domestic water demand that can be met in a given location of certain rainfall characteristics, by harvesting rain water. Twenty six locations in 26 of the 36 states of Nigeria were ~~studies~~. As shown in Table 1, all the six geopolitical zones as well as the major ecological zones were adequately represented in the study. Nine of the locations fall within the rain forest zone and are distributed as follows: five in the south south, two in the southeast and two in the southwest. Six of the locations fall within the derived guineas savanna and are distributed as follows: three in the southwest, one in the southeast and two in the north central. There are two locations in the northern guinea savanna (one each from the northeast and northwest) and one location in the southern guinea savanna. Four of the six locations in the arid/semi arid zone belong to the northwest while the other two belong to the northeast. Two of the locations (one in north central and one in the northeast) are located in the montane forest/grassland.

Monthly rainfall data spanning between 17 and 30 years were obtained for each location and the average coefficient of variation of monthly rainfall was evaluated (Table 1). For each location, six classes of dwelling houses commonly available in Nigeria were considered. The roof plan area and number of occupants for a typical dwelling belonging to each class have been tabulated(Table 2). For each class of dwelling house in each location, three levels of water consumption were also considered. The three patterns of water consumption are full plumbing connection, water connection with pour flush toilet system and basic water need. The per capita water consumption values used are those given by Gleick (1996).

In order to determine the proportion of domestic water requirement that can be met by rainfall, a water balance approach was adopted. For a given location, water consumption pattern, dwelling type and year; water balance was performed on a per capita basis using the following procedure. In this preliminary study, we just sought to determine what proportion of water demand can be met solely by annual rainfall and monthly rainfall. Hence, for the annual

Table 1 Locations of study and their characteristics

Location	Calabar	Uyo	Owerri	PH	Benin	Akure	Warri	Onitsha	Lagos
Eco Zone	RF	RF	RF	RF	RF	RF	RF	RF	RF
CV	0.77	0.79	0.80	0.81	0.82	0.83	0.83	0.92	1.04
Geo Zone	SS	SS	SE	SS	SS	SW	SS	SE	SW
Years	24	17	31	21	23	21	22	22	20
Location	Oshogbo	Ibadan	Abeokuta	Enugu	Ilorin	Lokoja	Minna	Jos	Yola
Eco Zone	DGS	DGS	DGS	DGS	DGS	DGS	SGS	MFG	MFG
CV	0.85	0.88	0.89	0.93	0.97	1.02	1.08	1.09	1.18
Geo Zone	SW	SW	SW	SE	NC	NC	NW	NC	NE
Years	23	20	22	23	22	23	27	23	21
Location	Kaduna	Bauchi	Gasau	Kano	Katsina	Sokoto	Maiduguri	Nguru	
Eco Zone	NGS	NGS	A/SA	A/SA	A/SA	A/SA	A/SA	A/SA	
CV	1.22	1.30	1.37	1.49	1.50	1.55	1.57	1.76	
Geo Zone	NW	NE	NW	NW	NW	NW	NE	NE	
Years	27	23	27	27	27	26	23	22	

RF rainforest, *DGS* derived guinea savanna, *SGS* southern guinea savanna, *MFG* montane forest/grassland, *NGS* northern guinea savanna, *A/SA* arid/semi arid region, *SW* southwest, *SE* southeast, *SS* south south, *NE* northeast, *NC* north central, *NW* northwest

Table 2 Dwelling house types and their characteristics

Dwelling type	Roof plan area (m^2)	No of occupants	Roof plan area per capita (m^2)	Level of water consumption per capita/day		
				Full connection	Pour flush	Basic need
Bungalow	270	6	45	150*l* (54.8 m^3)	75*l* (27.4 m^3)	50*l* (18.25 m^3)
Duplex	189	6	31.5			
One storey (4 flats)	343	24	14.29			
Two storeys (6 flats)	343	36	9.53			
Three storeys (8 flats)	343	48	7.15			

balance, there will be no carryover of water from 1 year to another, only from month to month within a given year. Likewise in the monthly water balance, there will be no carryover from month to month. First, the inflow per capita for each month from January to December was determined by Eq. 1 below, using 90 % collection efficiency.

$$Inflow(I) = 0.9\,R_i \times \frac{Roof\ Area\,(A)}{No\ of\ occupants} \qquad (1)$$

R_i is the monthly rainfall for the i^{th} month. Since rainfall is not uniformly distributed throughout the year, it is necessary to determine the quantity of reserve needed to augment water supply during lean periods. Rainfall in Nigeria has a single maxima, hence the capacity of reserve (storage) needed can be expressed as:

Storage Capacity (SC) = maximum cumulative surplus − cumulative surplus at the end of the year. The surplus for each month was then computed by subtracting the per capita monthly demand from the sum of monthly inflow and water in reserve (Eq. 2)

$$CS_i = \begin{cases} 0 & (if\ CS_{i-1} + I_i - D_i <= 0)\ else \\ CS_{i-1} + I_i - D_i \end{cases} \qquad (2)$$

CS_i is the cumulative surplus for the current month, CS_{i-1} is the cumulative surplus for the preceeding month, I_i and D_i are the inflow and demand for the current month respectively. Equation 2 assigns a value of zero surplus to deficit. Water in storage (WS_i) was computed using Eq. 3. The first component of Eq. 8 simply implies that there is nothing to store if the sum of inflow for the current month(C_i) and water already in storage at the end of the preceeding month (WS_{i-1}) is less than demand for the current month (D_i). The second component states that if the sum of inflow and water already in storage is greater than the sum of demand and storage capacity, then the storage is full.

$$WS_i = \begin{cases} 0 & (if\ I_i + WS_{i-1} - D_i < 0)\ else \\ SC & (if\ I_i + WS_{i-1} - D_i >= SC) else \\ I_i + WS_{i-1} - D_i \end{cases} \qquad (3)$$

Since the aim in this study is not to maximize storage but to obtain just enough to meet water needs for the rest of the year, there is need to spill excess water. Spill for each month was computed using Eq. 4. The first component of Eq. 4 states that if the sum of inflow (I_i) for the i^{th} and water in reserve at the end of the preceeding month (WS_{i-1}) is less than the sum of demand for the i^{th} month and storage capacity(SC), then there will be no spill. Otherwise, spill is water remaining after demand has been satisfied and the storage is full.

$$SP_i = \begin{cases} 0 & (if\, I_i + WS_{i-1} - D_i < SC) else \\ I_i + WS_{i-1} - D_i - SC \end{cases} \quad (4)$$

$$DM_i = \begin{cases} D_i & (if\, I_i + WS_{i-1} - D_i >= 0) else \\ I_i + WS_{i-1} \end{cases} \quad (5)$$

The demand met for each month was computed using Eq. 5. Equation 5 simply states that the demand (D_i) for a given month is satisfied if the sum of inflow and water in storage exceeds demand; otherwise only a part of the demand is met using inflow and water in storage. The accuracy of the computation for a particular year was checked using the overall water balance expression given below.

$$WC_n + \sum_i^n I_i = \sum_i^n SP + \sum_i^n DM_i \quad (6)$$

Equation 11 states that the sum of water in reserve at the end of the year and total inflow is equal to the sum of total spill and cumulative demand for the year. The implementation of the above scheme (Eqs. 1–6) has been exemplified in Table 3a. All parameters in Table 3 are in m^3 per capita except for rainfall which is in mm. It should also be noted that the percentage demand met per capita is also the same for the whole dwelling since the computation was performed based on roof area available to one occupant.

In order to examine the adequacy of monthly rainfall to satisfy monthly demand, the water balance computation was repeated without allowing water from the preceeding month make up for the deficit of water in current month (Table 3b). This is captured in Eq. 7 which states that if inflow exceeds demand for the current month, then demand is satisfied; otherwise inflow meets only a portion of the demand, leaving a deficit.

$$DM_i = \begin{cases} D_i & (if\, I_i - D_i > 0) else \\ I_i \end{cases} \quad (7)$$

Once demand for a particular month is satisfied, whatever surplus is remaining is completely spilled, otherwise there is no spill (Eq. 8)

$$SP_i = \begin{cases} I_i - DM_i & (if\, I_i - DM_i > 0) else \\ 0 \end{cases} \quad (8)$$

Table 3b is obtained by applying Eqs. 1, 2, 7 and 8.

Equations 1–8 were coded in Microsoft Excel and used to evaluate the proportion of domestic water demand that can be met by rainfall. From Table 2, a total of sixteen (16) cases were examined for each location using both the annual and the monthly water balance approach (Table 3) for each year. For instance, for Calabar with 23 years of rainfall data, a

Q3 t3.1 **Table 3** (a) Sample annual water balance computation for bungalow using basic water need for Calabar in the year 1980; (b) sample monthly water balance computation for three storeys using basic water need for Calabar in the year 1980

	Month	(a)								(b)					
t3.2		Rainfall (mm)	Inflow/ capita	Demand/ capita	Cum surplus	Water in storage	Spill	Demand met	Unmet demand	Rainfall (mm)	Inflow/capita	Demand/ capita	spill	Demand met	Unmet demand
t3.4	January	40.00	1.62	1.52	0.10	0.10	0.00	1.52	0.00	40.00	0.26	1.52	0.00	0.26	1.26
t3.5	February	5.50	0.22	1.52	0.00	0.00	0.00	0.32	1.20	5.50	0.04	1.52	0.00	0.04	1.48
t3.6	March	126.50	5.12	1.52	3.60	1.45	2.15	1.52	0.00	126.50	0.81	1.52	0.00	0.81	0.71
t3.7	April	163.00	6.60	1.52	8.68	1.45	5.08	1.52	0.00	163.00	1.05	1.52	0.00	1.05	0.47
t3.8	May	316.10	12.80	1.52	19.97	1.45	11.28	1.52	0.00	316.10	2.03	1.52	0.51	1.52	0.00
t3.9	June	620.30	25.12	1.52	43.57	1.45	23.60	1.52	0.00	620.30	3.99	1.52	2.47	1.52	0.00
t3.10	July	364.10	14.75	1.52	56.80	1.45	13.23	1.52	0.00	364.10	2.34	1.52	0.82	1.52	0.00
t3.11	August	728.70	29.51	1.52	84.79	1.45	27.99	1.52	0.00	728.70	4.69	1.52	3.17	1.52	0.00
t3.12	September	500.50	20.27	1.52	103.54	1.45	18.75	1.52	0.00	500.50	3.22	1.52	1.70	1.52	0.00
t3.13	October	489.10	19.81	1.52	121.83	1.45	18.29	1.52	0.00	489.10	3.15	1.52	1.63	1.52	0.00
t3.14	November	198.10	8.02	1.52	128.33	1.45	6.50	1.52	0.00	198.10	1.27	1.52	0.00	1.27	0.25
t3.15	December	1.70	0.07	1.52	126.88	0.00	0.00	1.52	0.00	1.70	0.01	1.52	0.00	0.01	1.51
t3.16		3553.60	143.92	18.24		0.00	126.88	17.04	1.20	3553.60	22.85	18.24	10.29	12.56	5.68

(a) Reservoir capacity=1.45 m^3 /capita; percentage demand met=93.44 % (b) Percentage demand met=68.86 %

total of 368 cases were examined. After the computation, the percentage demand met was averaged over the total number of years of rainfall data available for each location for each of the sixteen (16) scenarios. For ease of interpretation and handling the resultant data was paired as follows: inflow versus roof plan area for each location; percentage demand met versus roof plan area; and percentage demand met versus coefficient of variation for all locations. It was observed that both inflow and percentage demand met are strongly dependent on the coefficient of rainfall variation of the location of interest. Hence, two-stage least square regression analyses were used to obtain general expressions for percentage demand met and inflow. The relationship between each of these parameters and coefficient of variation was conceived to be of the form

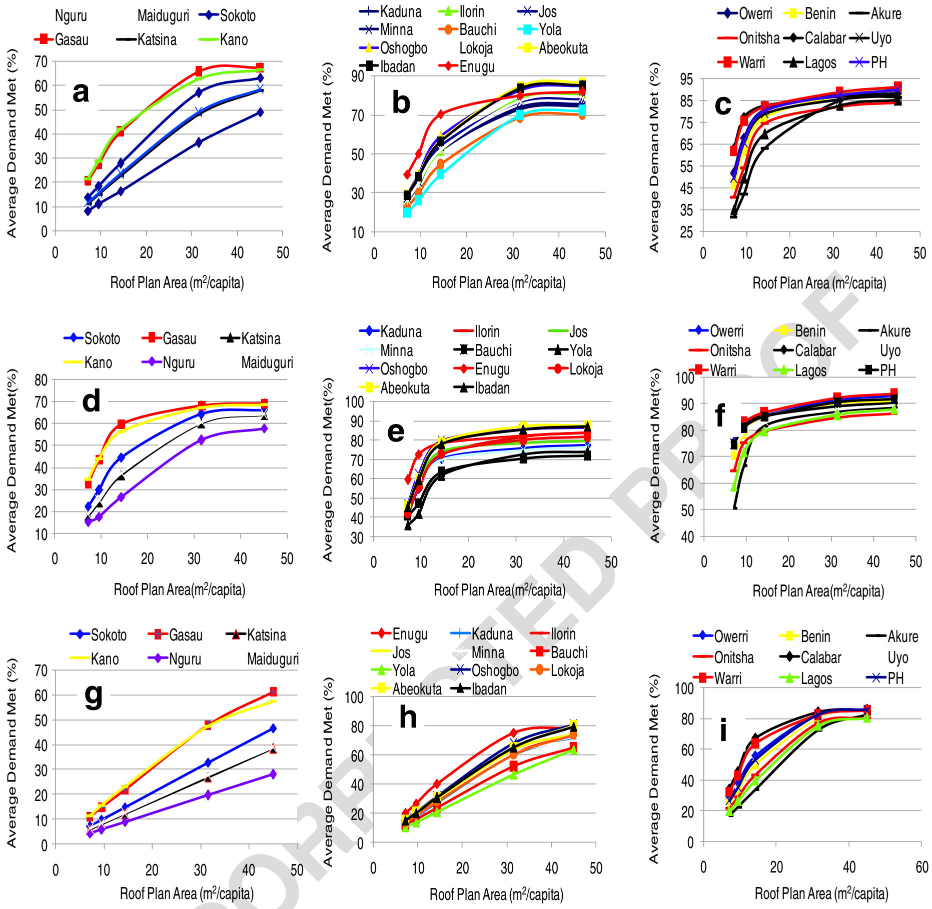
$$\Phi = \alpha CV^{-\beta} \tag{9}$$

Where Φ represents inflow(I) or percentage demand met(DM), and α and β are both functions of roof plan area per caita (A). First, each parameter was regressed against coefficient of variation for each house dwelling type which is represented by roof plan area per capita. Afterwards each of α and β was regressed against roof plan area per capita.

3 Results and Discussion

In this study, we have proposed rainwater harvesting, not only as a means of water supply, but also as a strategy for mitigating urban flooding especially in developing countries where stormwater drainage facilities are grossly inadequate or even nonexistent in some places. Whether flooding will occur or not is not just a function of quantity of water released, but also the rate of release. Rainwater harvesting facilities serve as a distributed virtual equalization system for stormwater. Rainwater harvesting ensures that water is released to the environment at a rate it can cope with.

It is obvious from Figs. 1 and 2 that Nigeria has an enormous potential for water supply through rainwater harvesting. In the rain forest zone comprising of the whole of south south region, some parts of southeast and southwest, over eighty percent(80 %) of domestic water demand of those living in bungalows can be offset by rainwater. However, this value changes with water demand and house dwelling type represented by roof plan area per capita (see Table 2). These figures show that bungalows have the highest potential for rainwater harvesting followed very closely by duplexes, because of the high area of roof available to individual occupant. This implies that regardless of amount of rainfall, tall buildings have lower potential for rainwater harvesting. As one moves from the rainforest zone in the south to the arid zone up north and as water demand increases, the effect of house dwelling type on water harvesting potential becomes more pronounced. For Calabar and Warri in the rainforest zone, as much as 80 % of basic water demand can still be met for a three storey building of eight blocks of flats. As the water demand increases to full water connection level, there is a sharp reduction in demand met from 80 % to just about 40 % for the same class of dwelling. The same effect is also obvious in the savanna zones except that the derived guinea savanna and the Jos plateau have higher potentials for rainwater harvesting than the southern and northern guinea savanna. In the savanna zones comprising the derived guinea savanna, the southern savanna and northern savanna, at least seventy percent (70 %) of water demand for a bungalow can be met by rainwater harvesting. The exceptions are Yola in the southern guinea savanna and Bauchi in the northern guinea savanna where just a little above 60 % of water demand for full plumbing connection can be met by rainwater harvesting. There is an acute reduction in rainwater



Q4

Fig. 1 Percentage demand met for **a** arid/semi arid zone (PFA) **b** guinea savanna zones (PFA), **c** rainforest zone (PFA), **d** arid/semi arid zone (BNA), **e** guinea savanna zones (BNA), **f** rainforest zone (BNA), **g** arid/semi arid zone (FCA), **h** guinea savanna zones (FCA), **i** rainforest zone (FCA). *PFA* pour plush (annual balance), *BNA* basic water need (annual balance), *FCA* full water connection (annual balance)

harvesting potential with respect to three storey buildings because of the low roof area per capita. For this class of house dwelling, about 50 % of basic water demand can be met by rainfall except for the northern guinea savanna locations of Bauchi and Kaduna, and the southern guinea savanna locations of Yola and Minna. For full water connection, percentage demand met by rainfall is below 20 % in all but one location (Enugu). The arid semi arid zone lying between latitude 10°–14°N and longitude 4°–14°E, and having only 5 months of rainfall between May and September (Bashir, 2008 as cited by Abaje et al. 2012) has the lowest rainwater harvesting potential. Taking, for instance, Gasau and Kano in the arid/semi arid zone, about 68 % and 40 % of basic water demand can be met for a bungalow and a three storey building respectively. However, for full water connection, about 60 % and only about 13 % of water demand can be met for the for a bungalow and a three storey building respectively. For some other locations in the same zone such as Nguru, Katsina, Sokoto and Maiduguri, not even as much as 10 % of water demand can be met for a three storey given the same level of water

Q1

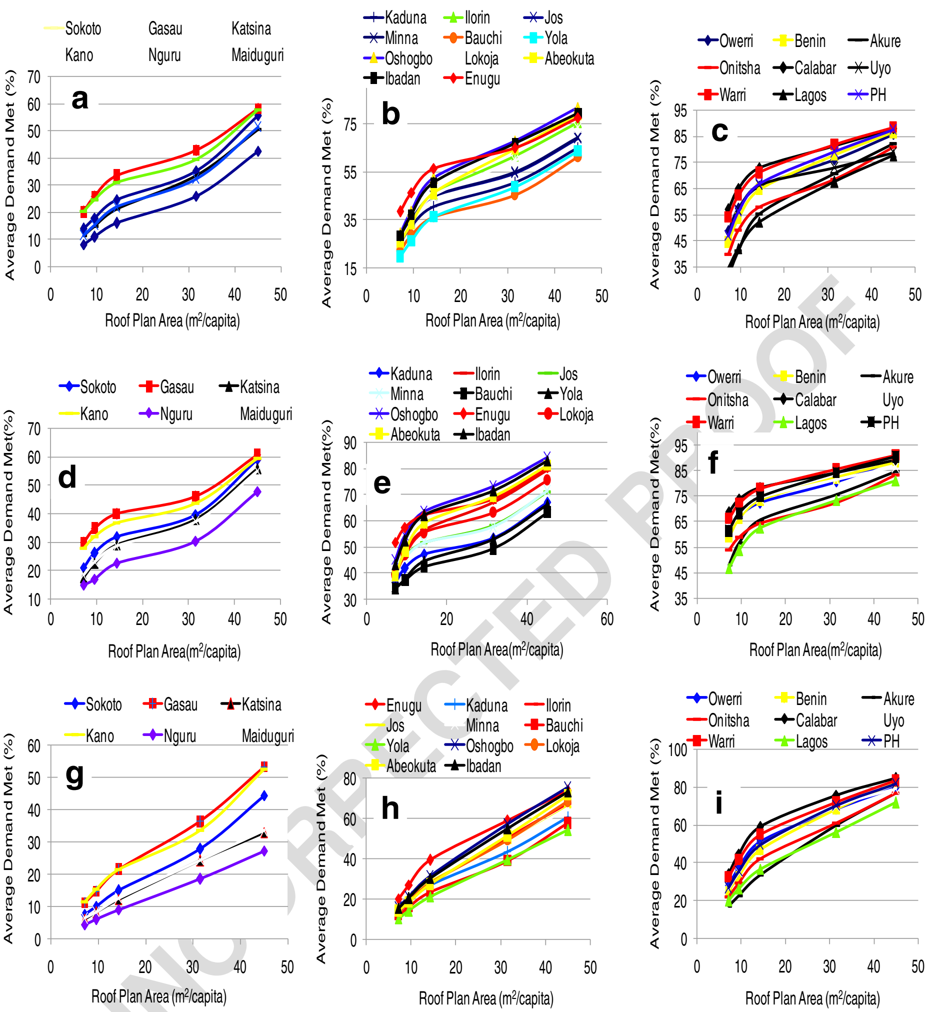


Fig. 2 Percentage demand met for **a** arid/semi arid zone (PFM) **b** guinea savanna zones (PFM), **c** rainforest zone (PFM), **d** arid/semi arid zone (BNM), **e** guinea savanna zones (BNM), **f** rainforest zone (BNM), **g** arid/semi arid zone (FCM), **h** guinea savanna zones (FCM), **i** rainforest zone (FCM). *PFA* pour plush (annual balance), *BNA* basic water need (annual balance), *FCA* full water connection (annual balance)

demand. These four locations are on the northern flank of the zone where annual rainfall is about 500 mm.

Figure 3 show that percentage of water demand that can be met by rainwater harvesting is strongly correlated with coefficient of rainfall variation (CV). First, it is to be observed that the difference between demand met using the annual water balance and the annual water balance is more pronounced towards the arid zone than in the rainforest zone. This is because the rainforest zone has almost enough monthly precipitation to meet monthly demand. This is not the case for the arid zone where there is need to store excess rainwater in a particular month for use in the following months. The coefficient of variation measures the uniformity in the distribution of monthly rainfall in a given location. A low value of CV implies a more even distribution of rainfall over the months; a value of zero would mean that there is no variation in

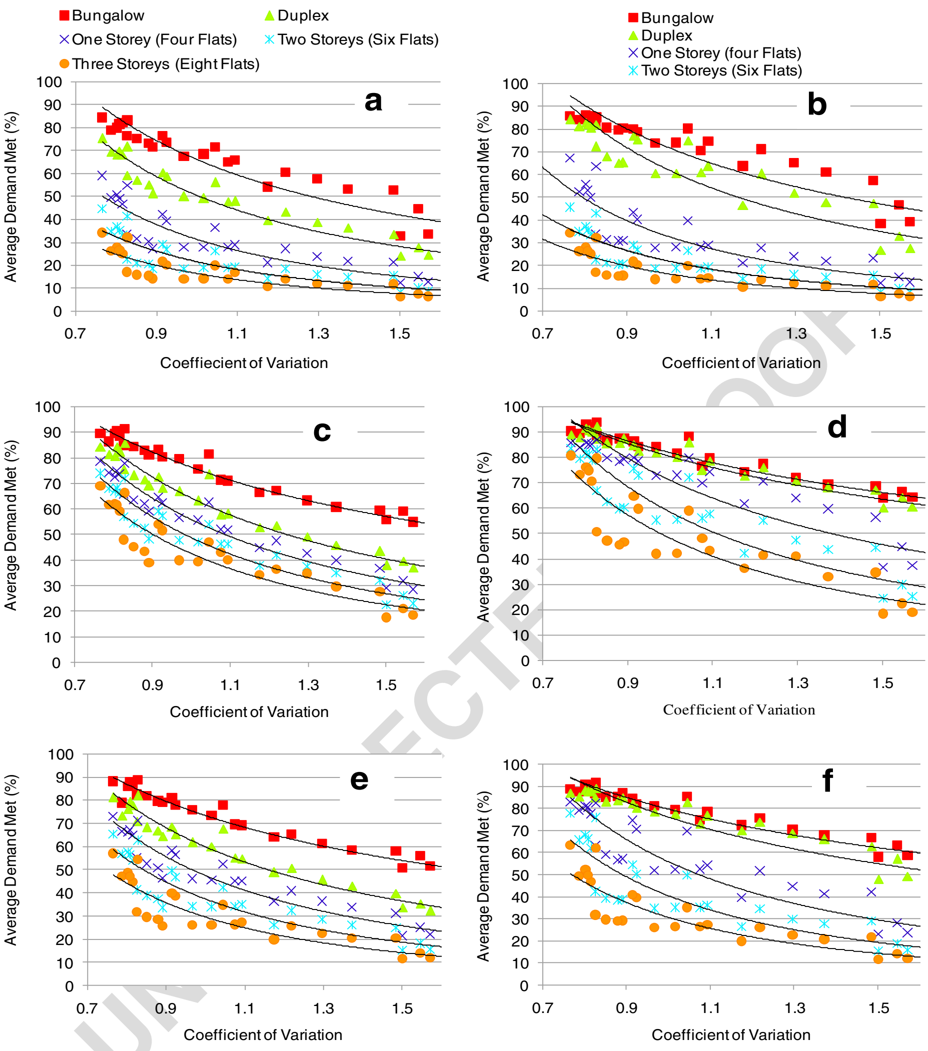


Fig. 3 Demand met versus coefficient of rainfall variation: **a** FCM **b** FCA **c** BNM **d** BNA **e** PFM **f** PFA. *FCM* full water connection (monthly balance), *FCA* full water connection (annual balance), *BNM* basic water need (monthly balance), *BNA* basic water need (annual balance), *PFM* pour flush (monthly balance) *PFA* pour plush (annual balance)

monthly rainfall or that there is no rainfall at all. From Table 1, it is obvious that the value of CV decreases from the rainforest zone in the south to the arid zone in the north. The coefficient of variation varies from 0.76 to 1.04 for the rainforest zone, 0.85 to 1.01 for the derived savanna, 1.08 to 1.18 for the northern guinea savanna, 1.21 to 1.3 for the northern guinea savanna and 1.37 to 1.76 for the arid/semi arid zone. These values depict the actual pattern of rainfall in Nigeria. There are two distinct season in Nigeria: the rainy season and the dry season. This distinction in season narrows progressively from the arid/semi arid zone to the rainforest zone where it rains almost all year round. Hence, locations with fewer months of rainfall have higher values of CV.

Figure 3 was produced by plotting percentage demand met against location denoted by coefficient of variation. All the lines are asymptotic to the horizontal axis; implying that demand met will tend to zero as CV increases infinitely, regardless of house dwelling type or water demand. However, demand met cannot become zero as long as there is rainfall. In the same vein, all the lines are asymptotic to the vertical axis, implying that as the coefficient of variation tends to zero, demand met increases infinitely. It is obvious that the relationship between demand met and coefficient of variation is a power function whose coefficient and index are both functions of roof plan area per capita. These coefficients and indices for different water consumption levels were obtained by two-staged least square regression analyses. The results are summarized on Table 4. For the annual water balance computations, both the coefficient (α) and the index (β) are linear functions of roof plan area per capita, having the general form. For the monthly water balance computations, α and β are both power functions of roof plan area per capita. Hence, the general form of the expression for demand is presented as Eqs. 10 and 11 for annual and monthly water balance computations respectively.

$$DM = (a + bA)CV^{m+nA} \tag{10}$$

$$DM = aA^{b}CV^{mA^{n}} \tag{11}$$

Where *a, b, m* and *n* are constants that depend on the level of water consumption or demand. The values of α and β for the cases studied are presented on Table 4 below.

From this study, there are various factors that determine the proportion of water demand that can be met by rainwater harvesting. The first is the roof plan area per capita. For a given level of water consumption, it is possible to maximize demand met by increasing the roof plan area per capita accordingly. However, this is not an economically viable option, especially in developing countries. An alternative approach will be to have an integrated rainwater harvesting system that combines roof catchment with overland catchment. By using different catchment such as cement-paved courtyards, compacted land and road surfaces in addition to roofs, rainwater can be effectively collected for storage (Zhu et al. 2004). Since bungalows and duplexes have much higher rainwater harvesting potentials taller building, it is better to use these categories of building for residential purposes in the arid/semi arid areas prone to acute water scarcity. Fortunately, land is not a problem in these areas as they have extensive land mass. Unfortunately, many low and middle income earners live in storey building consisting of blocks of flats, which possess lower roof area per capita than bungalows and duplexes. Another important factor that determines water demand met is the coefficient of

Table 4 Least square parameters for demand met and inflow

Level of consumption	Case	α	R^2	β	R^2
Full connection	Monthly	$1.273A+9.793$	0.989	$0.019A-2.013$	0.992
	Annual	$3.452A^{0.818}$	0.989	$-3.37A^{-0.3}$	0.847
Pour flush	Monthly	$1.051A+26.84$	0.956	$0.025A-1.933$	0.978
	Annual	$12.65A^{0.506}$	0.936	$-7.523A^{-0.64}$	0.960
Basic need	Monthly	$0.797A+40.34$	0.955	$0.02A-1.671$	0.958
	Annual	$30.86A^{0.271}$	0.881	$-6.708A^{-0.68}$	0.986
Inflow	All cases	$1.252A+0.008$	1	−1.86	–

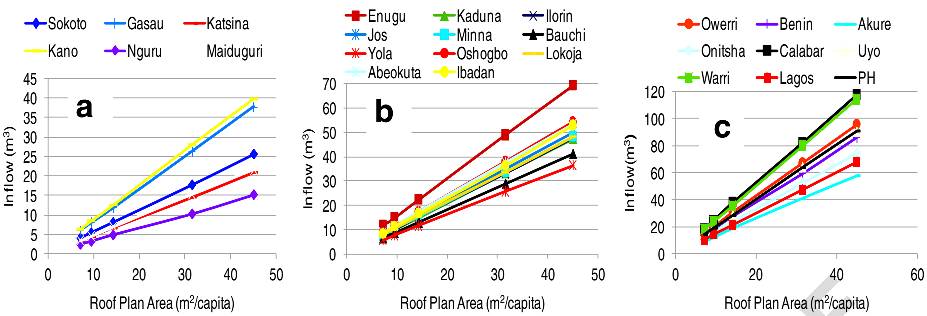


Fig. 4 Annual inflow versus roof plan area per capita **a** arid/semi arid zone, **b** guinea savanna zones, **c** rainforest zone

variation. From Fig. 3, rainwater harvesting potential approaches 100 % as coefficient of variation tends to 0.7. Figures 4 and 5 as well as Table 4 can be used to determine the rainwater harvesting potential of a location in Nigeria for any class of house dwelling. These tools can be used to make a quick assessment of rainwater harvesting potential for the purpose of planning municipal water supply schemes. For full water connection, the curves for the five categories of house dwellings diverge at the upper end (low CV) and converge at the lower end (high CV). However, reverse is the case for basic water need. For pour flush level of water consumption, the curves are almost parallel to one another. This shows that as water demand increases, the effect of house dwelling type on demand met decreases as one moves from the rainforest zone to the arid zone. But as water demand decreases, the effect of house dwelling type on demand met increases from the rainforest zone to the arid zone. Hence, the level of water consumption or demand is also an important factor affecting the proportion of demand that can be met by harvesting rainwater. The more the per capita demand, the less the demand met.

Rainfall is the most important factor that affects rainwater harvesting potential. The combined effect of rainfall and roof area per capita is inflow (Fig. 4). It is obvious from Fig. 4 that if a storage facility is installed, it is possible to satisfy full connection demand for a bungalow in all the rainforest locations. This is because total annual inflow exceeds the annual water demand. This is also the case for some locations in the guinea savanna. For the arid zone,

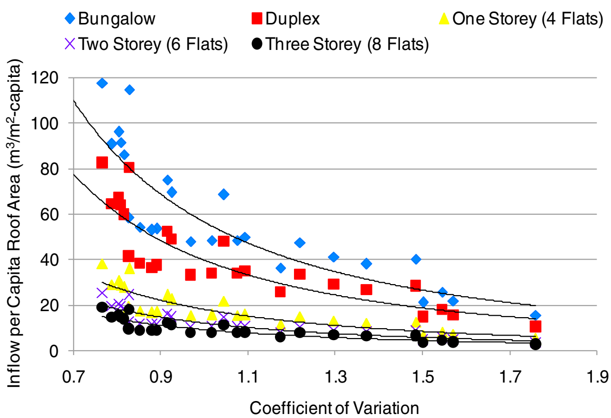


Fig. 5 Inflow versus coefficient of variation for different house dwelling types

Fig. 5 shows that there is a strong correlation between inflow and rainfall coefficient of variation. A general expression between inflow and coefficient of variation was obtained for the whole country, and is expressed as:

$$I = (1.252A + 0.008)CV^{-1.86} \quad (12)$$

The five points of roof plan area in Fig. 4 represent the five types of house dwellings presented in Table 2, in increasing order. Figure 4 shows that all the locations in the rainforest zone and some locations in the derived guinea savanna have enough inflow to satisfy water demand of those living in bungalows, even at full water connection level of consumption. However, the inflow drastically reduces, approaching zero, as the building progressively gets taller.

4 Conclusion

Rainwater harvesting is a viable option for water supply and a cost effective mitigation measure for urban runoff. This study shows that rainwater can serve as the main source of water supply for bungalows and duplexes in any part of the country, with percentage of water demand met increasing from the arid/semi arid zone to the rainforest zone. However, for tall buildings consisting of blocks of flats with low roof area per capita, rainwater can only serve as a supplementary source of water supply. Generally, rainwater harvesting potential of any location is a function of rainfall coefficient of variation, level of water consumption and roof area per capita. Rainwater harvesting potential can be increased by adopting an integrated rainwater harvesting system that combines roof catchment with over land catchment. It is therefore suggested that residential building design should incorporate rainwater systems which will go a long way in alleviating water stress being currently experienced in many parts of the country.

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