GUTTERING SYSTEM DESIGN FOR RAINWATER HARVESTING APPLICABLE FOR IBADAN METROPOLIS, NIGERIA

E.B. Lucas, K. Ogedengbe and T.P. Abegunrin

Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.

ABSTRACT

The study is on Ibadan (Nigeria) water supply which lags dangerously behind the demands of the fast-increasing population now put at about 5million. Since one source is proving inadequate, an Integrated Water Management Scheme (IWMS) is proposed, to accommodate surface and bore-holes as well as rainwater. Guttering, a vital aspect of rainwater harvesting, gulps up to 50% of the cost of rainwater harvesting. This work, on Guttering System Design for Ibadan, has the objective of producing a more efficient and cost-effective design. Rainfall data for 24 years (1980-2003) were collected. The probabilities of exceedence and the return periods of the data were calculated using Weibull Plotting Position Formula. The Coefficient of Variation was found to be as low as 17%. The return period of 1.92 years ensures the reliability of the rainfall pattern of Ibadan. A rainfall intensity of 2mm/minute mreasured for any given rain, was used in the design of the gutter and downpipe, using the long established Manning's formula. Ibadan has a bimodal rainfall pattern with annual rainfall intensity of 0.0025mm/minute and with erratic pattern between November and February. Rainfall amount not less than 1315.7mm has a return period of 1.92 years justifying using 1310mm mean annual rainfall in the design. A semi-circular PVC pipe was used in the design. Gutter diameter as a function of roof area, roof type and slope was found to conform to the equation:

$$d_g = 2.445 \times 10^{-2} [A_r C_r \cos\theta]^{3/8}$$

where;** d_g **= gutter diameter (m),** A_r **= roof plan area (**m^2**),** C_r **= run-off coefficient,** θ **= roof slope (degrees)

The downpipe diameter was found to be $d_d = 3.08 \left(\frac{C_r A_r}{h^{1/2}} \right)^{1/2}$

The design gives an efficient shape and configuration, about 20% above what is generally in place as gutter for rainwater harvesting in some buildings in Ibadan.

INTRODUCTION

Potable water is supplied to Ibadan from municipal source (pipe-borne), boreholes and wells. The municipal supply via Asejire and Eleyele dams is highly intermittent. This has resulted in the corrosion and leakages of pipes and pollution of water conveyed. Sinking of boreholes and wells has considerably increased withdrawal of underground water without a corresponding recharge. The depletion of undergound aquifer increases the risk of natural disasters such as land subsidence. Untreated and partially treated effluents from industries, wastes from animal slaughtering houses and domestic wastes are being discharged into surface water. These have limited the appropriateness of surface water for domestic consumption except after costly treatments. Water from rain has to be properly handled in order that it may not constitute menace in the form of erosion or flood as the case of Ogunpa river flood disaster in Ibadan in 1980.

Substantial works continue to be undertaken into water supply in various parts of the world, and many reports have been made about the present and future water supply for its various purposes. Shiklomanove (1998) observed that the availability of renewable water resources of the world will fall from an average of 7,800m^3/person/year in 1990 to 4,800m^3/person/year in 2025. Thus, there will be an increase in the number of people without access to safe water in parts of the world, where limited water supply, rapid population growth and water infrastructure lag behind population growth (Katerere, 1999). Gallopin and Rijisberman (1999), foresee a high water stress looming in many countries, mainly in Africa, South and East Asia and the Middle East. This calls for a greater water management and integrated water resources management (Katerere, 1999).

The population of Ibadan estimated at 5 million (NPC, 1991) which is ever increasing, has exceeded the available water resources in place. Developing new water resources facility is costly and there is a need to look for a cheaper and environmentally friendly means of supplying (potable) water to avert the impending water stress. Rainwater harvesting is one of such methods. Its integration into domestic water supply, if scientifically explored, will substantially improve the supply situation of good quality water at an affordable cost. Although, there may be doubts on attempts to forecast future water supply via rainfall due to climatic changes, a good study of the past rainfall data for a reasonable number of years (say 20 years) may give some indication on the rainfall situation of the concerned location, in this case Ibadan, and thus a reasonable forecast of the available water from rainfall.

Due to the importance of water to life and non-availability of sufficient water resources facilities, many have resorted into sourcing for supply through various means including through vendors. Water from these sources should be used with great care and caution. According to Hoeskra (1995), water – borne diseases such as schistosomiasis, diarrhea, cholera, etc still account for at least 80% of all illness in the developing countries.

Beyond the risk of land subsidence, underground water from boreholes and wells is not contamination – free. Chilton (2003) reported that in parts of major cities in developing nations, urban waste water is sometimes discharged untreated or partially treated into surface water course which in turn acts as conduits for taking effluents away from centre. He further stated that domestic and industrial effluents may directly be disposed off into the ground through septic tanks or disposal wells, which eventually pollute the underground water. Ibadan is one of the major cities that are so affected. Rainwater, as it is coming from the sky, is believe to be the purest form of water. Thus rainwater collected from clean surface and kept in a clean storage tank can be directly used for domestic purpose including drinking. It is however advisable to filter and boil the water so collected because it may have come in contact with contaminants, such as bird droppings, as it runs on the collecting surfaces (Coombes et al, 2002).

In roof rainwater harvesting, according to Still and Thomas (2002), gutters are an almost essential but relatively cheap part of the system. The purpose of gutter is to intercept and convey rainwater to the storage through downpipe. Still and Thomas (2002) further reported that the humid tropics are characterized by three feature that affect gutter design. These three features are: rainfall which could be intense the dry season is not long household incomes are low Rainfalls of high intensities require gutters of relatively high flow capacities and thus a design norm equivalent to rainfall of intensities 1.5 to 2.0 mm/minute are recommended (Still and Thomas, 2002). Short dry season requires small storage tanks, which will be relatively cheap, and the low household incomes will require low-cost rainwater harvesting systems. Thus, there is a need to pay attention to minimizing guttering cost.

According to Gould and Nissen – Petersen (1999), there are many inadequacies in guttering often resulting in the loss of over 50% of potential water yield. They reported that gutter slopes may be inadequate or even negatives, joints may leak, twisting of gutter sections and blockage by debris. Another common "future" in rainwater harvesting system is the oversize gutter and downpipe which invariably increase (unnecessarily) the cost of rainwater harvesting system. Roof slopes are considered to be among many factors that are affecting gutter size (Still and Thomas, 2002). Abegunrin (2004) found that roof slopes of between $20^0$and 30^0, which is common in the tropics, have little or no effect on the gutter size (Table I and II).

Table 1: Calculated Gutter sizes for Different Selected Roof Areas, Roof Types (Asbestos and iron sheet) and slopes.

(a) Gutter sizes for 20^0 slope

Roof Area (m^2)	Gutter Diameter (mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	77	80
50	99	103
75	118	120
100	129	134

(b) Gutter sizes for 25^0 slope

Roof Area (m^2)	Gutter Diameter (mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	76	79
50	98	102
75	114	119
100	179	132

(c) Gutter sizes for 30^0 slope

Roof Area (m^2)	Gutter Diameter (mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	74	77
50	96	100
75	112	117
100	125	130

Table 2: Calculated Downpipe sizes for Different selected Roof Areas, Roof Types (Asbestos and iron sheet) and Height (a) Downpipe sizes for 4m height

Roof Area (m^2)	Downpipe Diameter(mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	15.50	16.33
50	21.91	23.10
75	26.84	28.29
100	30.99	130

(b) Downpipe sizes for 8m height

Roof Area (m^2)	Downpipe Diameter(mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	13.03	13.73
50	18.42	19.42
75	22.57	23.79
100	26.06	27.47

(c) Downpipe sizes for 16m height

Roof Area (m^2)	Downpipe Diameter(mm)	
	Asbestos (C_r=0.9)	Iron sheet (C_r=1)
25	10.95	11.55
50	15.50	16.33
75	18.98	20.01
100	21.91	23.1

Of the three features affecting rainwater harvesting system mentioned earlier, low household income has a direct effect on the adoption or otherwise of rainwater harvesting technology. An appropriate sizing of gutter and wonpipe is therefore required. Over-sizing should be avoided to reduce the cost of the system to the barest practical minimum; undersizing should be avoided too to reduce the loss of potential water yield.

MATERIALS AND METHOD

Collection of Data

Rainfall data for Ibadan between 1980 and 2003 inclusive were collected from the International Institute of Tropical Agriculture (IITA), Ibadan. The data for the 24 years period were arranged in a descending order and the probability of exceedence for each value was calculated using the Weilbull plotting position formula

$$P = {}^{m}/_{(N+1)} \quad \ldots\ldots\ldots\ldots \quad 1$$

where

P = Probability of rainfall amount being equal to or exceeded (see table V)

m = assigned order number (m = 1,2,3 ....,24)

N = number of years of record i.e. 24

The mean monthly rainfalls over the period were calculated. Standard Deviation and the Coefficients of Variation were calculated.

The mean annual rainfall intensity for each year was calculated according to the formula

$$i_{mean} = \frac{R_a}{365 \times 24 \times 60} \quad \ldots\ldots\ldots\, 2 \quad \text{(Still and Thomas, 2002)}$$

where

i_{mean} = mean annual rainfall intensity (mm/min)

R_a = annual rainfall value (mm)

Thoery

Water flow in gutters, according to Still and Thomas (2002) depends onthe material of the gutterthe geometric shape of the gutterthe roof dimension and rainfall intensity.

In this work, a semi-circular PVC gutter was used. The Manning's coefficient of n=0.0015 was used as recommended by Still and Thomas (2002).

The quantity of flow conveyed by gutter is given as

$$Q_g = I\, C_r A_r \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

where

Q_g = flow in the gutter m^3/s

I = rainfall intensity (mm/s)

C_r = runoff coefficient (ratio)

A_r = roof plan area (m^2)

The value of I=2mm/min was used as recommended by Still and Thomas (2002). In sizing the gutter, the long established Manning's formula was used and it was assumed that the flow approaches a constant flow. Manning's formula is given as

$$V_g = {}^{1}/_{n}\, R_g^{2/3} S_g^{1/2} \quad \ldots\ldots\ldots\ldots\ldots \quad 4$$

And the continuity equation gives

$$Q_g = A_g V_g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5a$$

$$Q_g = {}^{1}/_{n}\, R_g^{2/3} S_g^{1/2} A_g \quad \ldots\ldots\ldots\ldots\ldots\ldots 5b$$

where

Q_g = Discharge (m^3/s)

A_g = X-sectional area of the gutter (m^2)

n = Manning's roughness coefficient (n=0.0015)

R_g = gutter hydraulic radius (m)

$=A_g/P_w$

P_w = wetted perimeter (m)

S_g = gutter slope (s =40% according to Still and Thomas, 2002)

v = velocity of flow (m/s)

The roof plan area, A_r and the gutter x-sectional area are related by the equation.

$$A_r = \frac{1}{nC_r I \cos\theta} S_g^{1/2} R_g^{2/3} A_g \quad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

where

A_r = roof plan area (m^2)

n = Manning's co-efficient

C_r = runoff coefficient

I = rainfall intensity (mm/minute)

θ = roof slope (degrees)

S_g = gutter slope

R_g = gutter hydraulic radius (m)

A_g = gutter area (m^2)

The velocity of water in a vertical downpipe was considered as that of a freely falling object, given as

$$v = \sqrt{(2gh)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

where

v = velocity (m/s)

g = acceleration due to gravity (m/s^2)

h = height through which water falls
= height of the downpipe (m)

The above relations were used and the diameter of half PVC gutter as a function of C_r, A_r and θ was found to be

$$d_g = 2.445 \times 10^{-2} (A_r C_r \cos\theta)^{3/8}$$

The diameter of the downpipe was found, as a function of C_r, A_r, and h, to be

$$d_d = 3.08 \left(\frac{C_r A_r}{h^{1/2}}\right)^{1/2}$$

This value, according to Still and Thomas (2002) is applicable to long pipes where secondary effects such as bends and joints are neglected. For short pipes, a factor of safety of 1.5 is adequate.

RESULTS AND DISCUSSIONS

Table III and Figure I show that Ibadan has a bimodal rainfall pattern, peaking in July and September. Table IV shows that the mean annual rainfall intensity for Ibadan between 1980 and 2003 was 0.0025mm/min. This was similar to the findings of Still and Thomas (2002) in Kampala, and thus a rainfall of 2mm/minute at any particular moment was used in the design.

Table III further shows that, on the average, there was no month when there was no rain in Ibadan, though the amounts in the months of November through February the following year were small. The Coefficients of Variation for these months were high (above 60%). This shows an erratic pattern during these months. However, the value of Coefficient of Variation for the year as a whole is much lower (17%). Table V shows that for rainfall amounts greater than or equal to 1315.70mm, the probabilities of exceedence are high (above 50%) and thus a lower return period of less than or equal to 1.92 years. This ensures the reliability of the use of mean annual rainfall of 1310mm in the design.

It was found that the gutter size depends on the roof area, roof type and roof slope. Asbestos sheets, having smaller runoff coefficient (C_r) than iron sheets, will require smaller gutter diameter than for iron sheet roof of the same area. Table I and II show that the effect of slope is not significant between $20^0$and 30^0 roof slopes. According to Still and Thomas (2002), the common roof slopes in the tropics range between $22^0$and 30^0.

Roof type and area have direct influence on the sizes of the downpipes while the height of the downpipe has an inverse relationship with the diameter. Taller buildings will require smaller diameter pipes than those for bungalows.

Table 3: Rainfall Data for Ibadan between 1980 and 2003 inclusive

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Value
1980	0.00	26.20	52.10	50.10	193.00	133.20	203.80	367.80	248.90	208.40	66.70	0.00	1550.20
1981	0.00	6.00	61.70	101.10	143.80	229.10	170.10	49.30	250.00	145.60	0.00	0.00	1156.70
1982	1.60	41.60	92.80	88.10	124.40	166.70	137.00	75.60	66.10	102.30	9.10	0.00	908.30
1983	0.00	3.90	3.20	81.0	310.90	160.80	108.60	36.10	139.30	38.30	28.60	85.90	996.60
1984	0.00	2.70	90.10	85.40	311.00	136.30	103.90	262.90	186.00	127.70	54.40	0.10	1360.50
1985	0.80	0.20	117.00	140.00	162.20	149.50	375.70	226.60	296.80	166.50	36.70	1.00	1673.00
1986	320	49.10	94.90	94.80	148.70	262.10	152.40	33.00	215.10	179.20	0.50	0.00	1233.00
1987	10.00	10.60	139.80	67.90	132.70	224.20	201.80	313.50	328.90	225.80	0.00	0.20	1655.40
1988	0.30	32.00	93.60	203.90	105.00	293.50	168.10	86.10	274.50	259.00	14.30	10.40	1540.70
1989	0.00	23.50	67.20	62.20	160.60	195.20	234.00	188.5	199.70	137.40	0.00	0.00	1268.30
1990	0.60	19.20	1.00	184.90	170.10	83.00	207.60	73.50	208.40	132.60	3.60	65.40	1149.90
1991	0.00	44.40	15.70	137.00	245.40	221.00	309.70	135.30	160.40	129.10	1.60	3.80	1413.40
1992	0.00	0.00	56.90	140.30	97.10	178.40	222.20	60.90	226.10	187.90	4.60	0.00	1174.40
1993	0.50	59.00	79.00	50.30	159.70	185.60	135.80	122.10	220 .90	157.70	51.50	2.00	1324.10
1994	2.40	9.20	52.00	57.90	101.30	76.10	163.80	75.00	252.70	271.71	16.30	0.00	1078.40
1995	0.00	1.00	144.50	174.20	209.10	147.70	216.80	159.40	212.80	142.20	36.80	7.40	1451.90
1996	2.10	34.80	76.00	140.90	115.10	102.10	227.20	170.60	333.20	148.30	0.00	0.00	1350.30
1997	0.60	0.00	105.50	150.90	155.10	177.30	71.60	96.10	195.80	261.00	38.20	33.80	1285.90
1998	0.00	2.80	8.00	54.40	82.60	158.00	71.80	60.90	143.50	198.80	32.20	11.30	749.30
1999	0.00	86.30	105.30	176.80	130.60	255.70	268.00	101.30	181.40	310.70	37.40	0.00	1653.50
2000	11.70	0.00	97.00	124.50	88.30	165.40	233.10	253.20	236.20	166.30	0.00	0.00	1315.70
2001	0.00	11.90	69.30	93.80	154.80	328.00	177.80	83.80	299.70	52.40	2.00	0.00	1269.50
2002	0.50	0.50	43.50	124.95	171.25	203.70	402.90	183.75	129.30	198.55	34.50	0.00	1493.40
2003	22.05	77.30	15.50	125.40	82.30	170.25	111.65	67.95	387.15	210.25	72.25	0.00	1342.05
Mean	**2.35**	**22.73**	**74.23**	**112.95**	**156.46**	**183.45**	**235.64**	**136.80**	**244.70**	**172.40**	**22.88**	**9.22**	**1310.00**
S.D*	**5.07**	**25.12**	**45.66**	**44.80**	**60.97**	**60.39**	**195.33**	**89.80**	**71.32**	**63.71**	**22.40**	**21.47**	**224.21**
CV**	**2.16**	**1.11**	**0.62**	**0.40**	**0.39**	**0.33**	**0.83**	**0.66**	**0.32**	**0.37**	**0.98**	**2.32**	**0.17**

* SD = Standard deviation

** CV = coefficient of variation = SD/mean.

Source:- IITA Ibadan, 2003

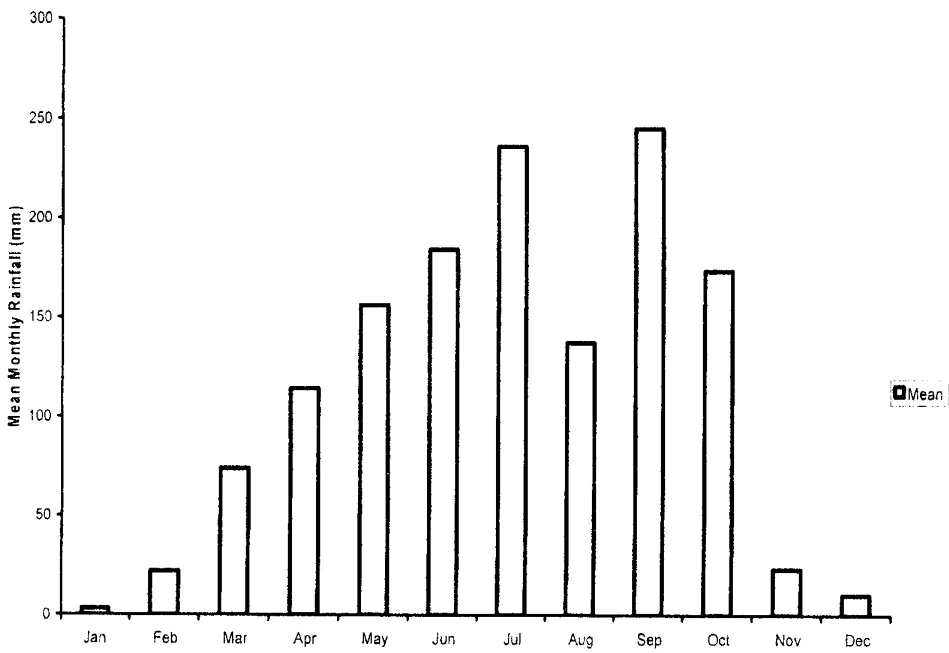

Figure 1: Graph of Mean Monthly Rainfall of Ibadan between 1980 and 2003 inclusive showing Bimodal Rainfall Distribution

Table 4: Calculated Mean Annual Rainfall Intensities for Ibadan between 1980 and 2003 Inclusive.

Year	Rainfall Annual Value, R_a (mm)	mean intensity i_{mean} (mm/min)
1980	1550.20	0.003
1981	1156.70	0.002
1982	908.30	0.002
1983	996.60	0.002
1984	1360.50	0.003
1985	1673.00	0.003
1986	1233.00	0.002
1987	1655.40	0.003
1988	1540.70	0.003
1989	1268.30	0.002
1990	1149.90	0.002
1991	1413.40	0.003
1992	1174.40	0.002
1993	1324.10	0.003
1994	1078.40	0.002
1995	1451.90	0.003
1996	1350.30	0.003
1997	1285.90	0.002
1998	794.30	0.002
1999	1653.50	0.003
2000	1315.70	0.003
2001	1269.50	0.002
2002	1493.40	0.003
2003	1342.05	0.003
mean	1310.00	0.0025

Table 5: Calculated Probability of Exceedence and Return Period of Rainfall Data for Ibadan between 1980 and 2003 Inclusive.

m*	Rainfall (mm)	Probability ($P = {}^{m}/_{N+1}$)**	Return Period (T = 1/P) (years)
1	1673.00	0.04	25.00
2	1655.40	0.08	12.50
3	1653.50	0.12	8.33
4	1550.20	0.16	6.25
5	1540.70	0.20	5.00
6	1493.40	0.24	4.17
7	1451.90	0.28	3.57
8	1413.40	0.32	3.13
9	1360.50	0.36	2.78
10	1350.30	0.40	2.50
11	1342.05	0.44	2.27
12	1324.10	0.48	2.08
13	1315.70	0.52	1.92
14	1285.90	0.56	1.78
15	1269.50	0.60	1.67
16	1268.30	0.60	1.56
17	1233.00	0.64	1.47
18	1174.40	0.68	1.39
19	1156.70	0.72	1.32
20	1149.90	0.76	1.25
21	1078.40	0.80	1.19
22	996.60	0.84	1.14
23	908.30	0.88	1.09
24	794.30	0.92	1.04

* m is assigned number in descending order of rainfall
** Weibull formula

CONCLUSIONS

From the results obtained, the following conclusions are drawn:

The sizes of gutters and downpipes required were found to be smaller than commonly used one. This has a cost – saving effect and makes rainwater harvesting more economical.

Since the effect of slopes is negligible for tropical building (between 22^0- 30^0), gutters and downpipes could be sized based on the roof plan area.

Based on the rainfall reliability of Ibadan and cost – saving advantage of the design (of gutters and downpipe), rainwater harvesting is a good potential for potable water supply in Ibadan.

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