Rain water harvesting; a pathway to achieving sufficiency in water supply and flood mitigation, Benin City perspective, Nigeria.

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Abstract:

Rain water harvesting is recognized as a key player in alleviating water problems, and it has proven effective especially for new projects when the rain water harvesting systems are optimized. This study emphasized the dual role of rainwater harvesting, such as water supply and flood reduction (using green roof as an eco-friendly harvesting measure for flood control). Annual rainwater harvesting potential determined for Benin City was 745.9m^3. Roof catchment area of 400m^2 and storage tank size of 400m^3 were obtained as appropriate for the high demand scenario of 65.880m^3 monthly demand. 86% reliability for this storage tank size was also obtained, while over 80% flow frequency reduction was obtained for the green roof applied as the measure for flood reduction. Green roof Sensitivity analysis indicated a less steep roof with shrub vegetation type is preferred for flow frequency reduction in controlling flooding. A green roof slope of 0.001 with shrub vegetation reduced flow frequency by over 90%

Key words: rain water harvesting potential, Benin, WWHM, rainfall, green roofs, flood control

1.0 Introduction

Water is scarce goods, this is a globally acknowledged fact, hence the current paradigm shift on demand management as a measure for water conservation. Like most African countries Nigeria is posed with enormous challenges in meeting the water requirement and demands of its teeming populace even though it is highly endowed with abundant water resources. A key resource in abundance in Benin City, Edo state of Nigeria is water, rainwater precisely. This state records and has high and long amount of rainfall, consistently above 2000mm annually and a rainy season spanning over six months. Predominant environmental problems within the state include, poor access to clean adequate public water supply, flooding and erosion which leads to pollution of water streams. Sanstrom,1997 asserted that it is no longer feasible in a long term , cost effective and environmental friendly manner to increase water supply by building additional dams, conveyance system, sinking new wells, constructing desalination plants, solutions must be found at the user end of the pipe i.e. increasing water use productivity ,reducing conveyance losses, re-using water and optimizing allocation. While adequate water supply remains a big challenge in the country, incidence of flooding has persisted, [22] reported that 31 states would experience devastating flooding with worst scenarios expected in Kogi, Edo, Delta and Anambra (This day live April 2013). Famous Obedi in his report (point blank news.com) highlighted the many incidence of flood experienced in the country that has caused serious damages to lives and properties, and most of which are direct consequence of river overflows due to high rainfall events. A.E Olajuyigbe, O.O. Rotowa, E. Durojaye(2012) assessed flood hazards in Nigeria, and also observed similar trends, Both studies indicated high rainfall events as major cause of floods. Eroksuz and Rahman (2010) investigated water saving potential of rain water tanks in multistoried residential buildings for 3 cities in eastern Australia, and concluded that appropriate sized Rain water tanks can provide significant water savings even in dry years. S.I Oni et al (2008) in their study identified the practice of RWH to be predominant in rural areas and the insufficiency of tank size utilized for harvesting, [5] ascertained that irrespective of rainfall amount and duration, roof area, design and slope are key determinants of harvestable rain water, steeper slopes and design with harvesting possible from all sides of roof harvest more water .Imteaze et al (2011) used a daily water balance model to optimize tank size for large scale roof catchment in Melbourne Australia, [16] reported that RW harvested and stored in the rainy season can supplement water demand in dry season, [11] showed that only 3% of sampled population in the northern Nigeria harvest rain water, [14] used a daily water balance model to design an optimal storage tank size for south west Nigeria, and obtained 100% reliability for a tank size of 7000L and 10000L for low and high demand scenarios respectively for toilet flushing and combined toilet and laundry use. David J. Sample and Jia Liu(2014) optimized rainwater harvesting systems for the dual purpose of water supply and runoff capture in Virginia US, and obtained 20% reliability target for commercial, office and high density residential cases which also had the lowest runoff unit cost, using RASP model. Chidozie and Nnennaya (2014) assessed RWH with focus on flood mitigation and domestic water supply in Nigeria. This paper aims to emphasize the relevance of the dual function of RWH (water supply for high density residential buildings and flood mitigation), bringing into perspective its flood control role, and seeks to add to the sparse knowledge existing in this regard. RWH in recent times has gained popularity and its emphasis among the several strategies for mitigating urban water crisis has proven effective especially when it is optimized. RWH if well practiced and implemented into water supply schemes has the potential of mitigating water problem, saving or reducing water cost as well as controlling storm water or flooding. This is true in view of the fact that all water originate from rainwater, and more so, because most cases of flood especially in Nigeria are consequent of high rainfall storm events. A proper harnessing of the high rainfall potential of this region would in the long run save mains water cost for various water utilization processes and purposes, while also reducing pressure on public water supply systems. The western Washington hydrology model (WWHM) is used in assessing the impact of green roof as contributory measures for storm water control). Other forms of harvesting that are ecofriendly include green roofs, permeable pavers, rain gardens, swales, etc., among these forms, Green roof has an additional aesthetic value advantage and it is relatively cheaper and not common in this part of the world. Most previous studies have focused exclusively on water supply.

2.0 Modes of eco-friendly rainwater harvesting.

Two specific modes of eco-friendly rain water harvesting are identified, namely active and passive modes.

2.1 active modes

This mode of harvestings is applicable for both residential and commercial structures, and mostly involves mechanical means for capturing, cleaning and storing rain water. It also reduces load on municipal sewer and storm water systems whilst reducing impact on the environment. The essence is to capture store and reuse water and involves the use of tanks, cisterns, rain barrels, etc.

2.2 passive modes

The passive mode serves basically to control water until they can naturally be absorbed or infiltrated back into the land. It usually doesn’t involve the use of mechanical methods for collecting, cleaning or storing water. There essence is to capture, store, slow, infiltrate run off while enhancing existing elements of your environment. They include permeable pavement, rain gardens, green roofs, compost and mulch, etc.

2.2.1 Permeable paving

Permeable paving is a surface layer that allows rainfall to percolate into an underlying reservoir base where rainfall either infiltrates underlying soil or removed by a subsurface drain. It is used on walk ways, patios, or drive ways and not only adds aesthetic value but also improves water quality by slowing runoff, and breaking down pollutants, as they contain void spaces that allow the storm water to flow from pavement surface to the sub base and into underlying soil.

2.2.2 Rain gardens

A rain garden is simply a shallow depression using soils and plants to manage runoff from impervious areas like roof, drive way. They are highly aesthetic and can hold several inches of rain water, while allowing storm water to slowly seep into the ground.it can also hold first flush rains which usually contains high level pollutants. Rain gardens collects, absorbs, and filter storm water runoff.

2.2.3 Green roofs

This are techniques for capturing rain water which generally consist of a membrane and drainage layer topped with a soil like growing medium and hardy plants, in simple terms they are buildings whose roofs are partially or completely covered by plants. Besides the aesthetic appealing nature of green roofs, the also improve air quality while capturing and slowing runoff. Residential scale version usually has a shallow soil profile and planted with sedums, and other low growing succulents. Residential scale version usually has a shallow soil profile.

2.2.4 Swales

A swale is like a ditch that is shallow, with wide conduit sloped gently basically to mimic conventional storm water conveyance and piping system. They are typically lined with landscaping materials like turf grass or native vegetation to help reduce peak flow rate of rainfall and are usually sited around parking lots, amongst others places.

3.0 Materials and Method

For this case study we proceeded first by determining the minimum appropriate roof size capable of harvesting enough water to meet the demand scenario. We considered a range between ($100m^2$-$600m^2$) which is consistent with the study conducted by [5] and typical of what is obtainable in the study area. Monthly rainfall data for a 22 year period (1980-2002) was utilized, obtained from Nigeria meteorological station Benin and a runoff coefficient of 0.9 for hard roofs in humid tropics. Thereafter simulations with various tank sizes in the range of 60-$400m^3$ where embarked on to make for optimized results. And then reliability curves were obtained for the system. Optimal values make for economic harvesting which is imperative especially when considering implementation of RWH on new projects. We assumed a 6persons house hold size based on a study survey by [13], a 60l/c/d water consumption considering water use for basic hygiene purpose only. This yielded a total monthly demand of $65.880m^3$ obtained by applying equation 1, eventually a spread sheet was simulated for the 22 year rainfall data for various roof and tank sizes, ($400m^2$ tank and roof size shown in table 2) assuming zero initial tank storage from the month of January, over flow was allowed as negative value was not allowed for tank storage hence volume of water in tank cannot be greater than tank size, months with zero tank volume i.e. $V_t = 0$ were regarded as failure months. Applying equations 5 the reliability curves for various roof and tank sizes of the system were obtained

The demand, supply, harvesting potential and the performance of RWHS mathematical models are generally based on mass balance equations, the following equations usually apply:

$D_t = n \times N \times d$ …………………………………………………………………….................... (1)

Where D_t is the total monthly demand or consumption, N is the number of house hold (flats), n is the number person per household, and d is average daily water demand

Harvesting potential $Q_t = A \times C_r \times R_f$ ………………………………………………………… (2)

Where A is contributing roof area (m^2), C_r is coefficient of run-off, and R_f is rainfall time series, daily, monthly or annual

$0 \le v_t = (v_t - 1 + Q_t - D_t) < v_s$ ……… ……… ....… .(3)

Reliability = (1- $\sum_0^r failure$ months/ $\sum_1^n months$) x 100% ………………………………… (4)

Or Re = (1-n/N) *100% ……………………………………………………………………...…….. (5)

CV = S_/X ………………………………………………………………………………………......(6)

Where v_t is present water tank volume, v_{t-1} is water tank volume remaining from a previous time step, D_t is total monthly consumption or demand, Q_t is captured or harvested water at current time, and V_s is volume or tank capacity. Re is reliability, n = number of failure months and N is total number of simulated months.CV is coefficient of variation , S_ standard deviation of monthly or annual rainfall in mm, and X is mean monthly or annual rainfall.

We investigated further the performance of green roof as a measure for storm water mitigation and control using the Western Washington hydrology model (WWHM). WWHM is similar to the EPA SWMM (storm water management model) which has been widely used for flood mitigation, [9].WWHM is simply another version developed and used for the Washington region, with basically similar modules and characteristics as the SWMM which is applied for single or long term simulations of runoff quantity and quality for primary urban areas. It tracks the quantity and quality of runoff made within each sub-catchment, flow rate, depth and quality of water in each pipe channel during a simulation period, which is made of multiple time steps. WWHM compares predeveloped and post developed routed runoff statistics with flow frequency for a 2year -100 year storm events. It also identifies water quality, flow rate and volume. The gray river hatchery in western Washington has same rainfall data and pattern as the study area, and falls under the Wahkiakum County hence its choice for use in running the model. A series of trials where conducted using the model for the purpose of obtaining a passable design.

Table I. Model inputs

Predeveloped pervious land	**Flat pasture A.B**	**1 acre**
Mitigated impervious land	Lawn	0.5 acre
	Roof area	0.25 acre
	Pond	0.25 acre
Green roof	Slope	0.001
	Roof length	2153ft
	Green area Depth of material	0.25 acre 4 in.
	Vegetation type	Shrubs

4.0 Results, analysis and discussion

Recognized key factors for determining rain water harvesting potential to satisfy any demand scenario are rainfall, catchment area, coefficient of variation, storage facility/ capacity and demand level. Rainfall considered probably the most paramount factor, is however somewhat unpredictable as man has little influence or control over its intensity, duration or amount. Catchment type, area and storage facility are fundamental factors that can be adjusted and managed, hence we explore their maximization and determine reliabilities of the simulated storage tank sizes for this case study. The reliability of any rain water harvesting system (RWHS) system is a measure of the probability of the system not failing or the sufficiency to supply the necessary amount of water [19]. It is the fraction of time in a typical simulation period that a tank hasn't run dry. Roof areas of $100m^2$-$300m^2$ all gave negative values for this demand scenario and clearly indicates that the minimum roof area capable of harvesting enough water to satisfy this demand case is $400m^2$. The negative values (on $100m^2$ -$300m^2$) indicate deficits in supply, and degree of deficits, table 3 also shows the number of failure months during the course of the year. The roof area range between 100-$300m^2$ harvested rain water inadequate to meet demand as there were a lot of failure months due basically to high water demand of this building. The total annual demand for this case is $790.6m^3$. $400m^2$ roof area annually harvest $745.9m^3$ rain

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water, 500m^2, harvest 932.m^3, and 600m^2 harvests 1118.3m^3 rain water respectively. At 400m^2 roof area, failure months is highly reduced as more water is harvested, when compared to the 100-300m^2 roof area range. Further still, with this roof area, a lot more water is harvested, especially in the months of July, September, and October, which allows for adequate savings if an appropriate storage sized facility is installed. This would enable and make for available water in shortfall months i.e. in the dry seasons around November down to February. This is possible due to the low rainfall coefficient of variation of this region (0.82), which implies a close or uniform distribution of rainfall. This reduces difference in monthly water harvestable .i.e. there is minimal shortage in monthly supply thus with an appropriate storage tank size, water in the rainy season especially in July, September, October can be stored and used to augment for the shortfall months. Although roof areas above 400m^2 harvest rainwater which supersede the demand case, proposing their use would translate to increase cost, and unnecessary waste via overflows which may also contribute to floods. Again, identified roof catchment areas for high density residential storey buildings in the country usually fall within the 300m^2 to 500m^2 range (A.O Eruola et.al 2010). Working with this range, tank sizes between 60m^3 to 400m^3 were simulated for the 22years rainfall time series resulting in a total of 264 simulation months. From table 3, for the 300m^2 roof area, 90m^3, 100m^3, 200m^3, 300m^3, and 400m^3 tank sizes resulted in 157, 155 and 144 failure months respectively, declining steadily and linearly. The reliability values for this tanks sizes correspond to 41%, 41.3% and 46% respectively. It is observed that only a marginal increase in reliability is obtained between the tank size of 90m^3 and 100m^3 (0.3%), and 5.7% from 100m^3 to 200m^3, however beyond 200m^3 storage tank size reliability remains constant irrespective of increase in tank size. This is another indication that the 300m^2 roof area is limited in its capacity to harvest adequate water for this demand scenario, thus any further increase in storage capacity would be insignificant and meaningless and off course cost ineffective. However with the 400m^2 roof catchment area, failure months dropped reasonably to 125 even with a tank size of 60m^3, resulting in a reliability of 53% an increase of 11.7% for a 30m^3 lower tank size. There is an increase of 18.7%(between the 300m^2 and 400m^2 roof catchment area from 41.3% to 60%) reliability at same 100m^3 storage tank size. From the table it is also evident that increasing further storage tank size under this roof catchment, reliability would yet increase as failure months would reduce. 400m^3 storage tank has the highest reliability of 86% at 37 failure months and 60m^3 storage tank has a reliability of 60% at 125 failure months. Worthy of note also is the fact that this roof catchment area, i.e. 400m^2 affords not only increased harvesting potential but also a wider range of storage size implementable, for increased demand scenarios.

Furthermore it is clear from table II and III that the storage tank size of 400m^3 could save reasonable quantity of water enough to balance and sustain forth coming months which are usually the critical months of January down to April. The 300m^2 roof catchment and 200m^3 storage tank was only able to save or contain water in the tank for 18% of the simulated period, while the months of February and March all ran dry throughout the simulated period. Water savings in the tank resumed from April at 18%, to 36% in May and increasing gradually and steadily for the 22 years simulated period until September at 86%, before gradually declining again to 36% in December. This is the reverse for the 400m^2 roof catchment with the 200m^3 and 400m^3 storage tank sizes.

Table II . Summary of water volume calculations for a roof area of 400m^2 and tank size of 400m^3 at the demand scenario of 65.880m^{3}Monthly consumption

Month	Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
J	RF	3.2	5.6	101.9	4.9	6.4	8.7	5.6	0.8	7	10	19.6	18.9	0.3	5.1	27.5		13	7	75.3	44.1	86.3	4	18.8
	Qt	1.2	2	36.7	1.8	2.3	3.1	2	0.3	2.5	3.6	7.1	6.8	0.1	1.8	9.9		4.7	2.5	27.1	15.9	31.1	1.4	6.8
	Vt	0	241.9	130.7	21.4	0	0	0	0	191.1	175.2	109	179.3	220.9	163.9	33.1		212.4	245.4	231.9	202.1	153.4	113.6	134.6
F	RF	58.3	6.8	111.4	49.4	45.8	16	45.1	74.5	71.1	25.8	18.8	58.1	0.2	9.6	14.6		50.6	92.6	80	1.8	64.4	73	10.1
	Qt	20.98	2.4	40.1	17.8	16.5	5.8	16.2	26.8	25.6	9.3	6.8	20.9	0.1	3.5	5.3		18.2	33.3	28.8	0.6	23.2	26.3	3.6
	Vt	0	178.4	104.9	0	0	0	0	0	150.8	118.6	49.96	134.3	155.1	101.5	0		164.7	212.8	104.8	136.8	110.7	74.1	72.3
M	RF	77.8	108.4	98.2	39	87.3	110.5	109.4	100.2	154.8	66.1	55	123.5	41.4	135	111.4		165.4	188.2	104	104.6	98.3	60.8	119.3
	Qt	28	39	35.4	14	31.4	39.8	39.4	36.1	55.7	23.8	19.8	44.5	14.9	48.6	40.1		59.5	67.8	37.4	37.7	35.4	21.9	42.9
	Vt	0	151.5	74.4	0	0	0	0	0	140.6	76.5	3.9	112.9	104.1	84.2	0		158.3	217.7	166.3	108.6	80.2	30.1	49.3
A	RF	140.4	119.8	211.4	76.8	59.3	33.2	52.3	112.5	136.5	152	256.8	386.9	222.7	95.4	149.8		217.9	298.2	230.9	104.8	119.6	170	394.3
	Qt	50.5	43.1	76.1	27.6	21.3	11.95	18.8	40.5	49.1	54.7	92.4	139.1	80.2	34.3	53.9		78.4	107.4	83.1	37.7	43.1	61.2	141.9
	Vt	0	128.7	84.6	0	0	0	0	0	123.8	65.4	30.4	186.1	118.4	52.6	0		170.9	256.3	183.5	80.4	57.5	25.4	125.3
M	RF	296.3	277.2	146	267.4	120.4	173.4	162.7	157.4	168	140.4	181.4	196.7	240	198.2	327.9		226.9	322.2	305.3	214.6	161.7	191.8	155.7
	Qt	106.7	99.8	52.6	96.3	43.3	62.4	58.6	56.7	60.5	50.5	65.3	70.8	86.4	71.4	118		81.7	115.9	109.9	77.3	58.2	69	56.1
	Vt	40.8	162.6	71.4	30.4	0	0	0	0	118.4	49.98	29.8	191	138.9	58.2	52.1		186.7	306.4	227.5	91.8	49.8	28.5	115.6
	RF	298.5	180.6	174.1	277.2	134.1	202.5	65.1	217	227	340	204.1	207.2	335.8	208.8	351.3		256.2	281.1	203.3	214.4	*	413.7	364.3
	Qt	107.5	65	62.7	99.8	48.3	72.9	23.4	78.1	81.7	122.4	73.5	74.6	120.9	75.2	126.5		92.2	101.2	73.2	77.2	*	148.9	131.1

J	Vt	82.4	161.8	68.2	64.3	0	7	0	12.2	134.3	106.5	37.4	199.8	193.9	67.5	112.7		213	391.7	234.9	103.2	0	111.5	180.8
J	RF	407.8	276.1	243.9	166.5	223.8	244.3	214.2	269.5	393	279.2	353.4	656.2	515.9	191.4	444.4		383.3	182.3	285	506.1	412.3	294.7	216
	Qt	146.8	99.4	87.8	59.9	80.6	87.9	77.1	97	141.5	100.5	127.2	236.2	185.7	68.9	159.9		137.9	65.6	102.6	182.2	148.4	106.1	77.8
	Vt	163.4	195.3	90.1	58.4	14.7	29	11.2	43.3	209.9	141.1	98.8	370.1	313.8	70.5	206.8		285.1	341.4	271.6	219.5	82.5	151.8	192.7
A	RF	482.3	230	66.8	142.8	181.8	305.2	117.7	722.5	191.2	427.8	614.5	382.6	76.4	433.9	461.2		580.8	392.3	258	95.6	232	237.9	137.4
	Qt	173.6	82.8	24	51.4	65.4	109.9	42.4	260.1	68.8	154	221.2	137.7	27.5	156.2	166		209.1	141.2	92.9	34.4	83.5	85.6	49.5
	Vt	271.8	212.2	48.2	43.9	14.2	73.1	0	237.6	212.8	229.2	254.1	400	275.4	160.8	306.9		400	400	298.6	188	100.1	171.5	176.3
S	RF	445.8	394.8	391	425.2	235.1	197.9	231.3	348.1	445.4	157.3	296.9	268	256.3	257.6	391.8		382.2	476	300	387.9	369	345	35.1
	Qt	160.5	142.1	140.8	153.1	84.6	71.2	83.3	125.3	160.3	56.6	106.9	96.5	92.3	92.7	141		137.6	171.4	108	139.6	132.8	124.2	12.6
	Vt	366.4	288.4	123.1	131.1	32.96	78.4	17.4	296.98	307.2	219.96	295.1	400	301.8	187.6	300		371.7	400	340.7	261.7	167.1	229.8	123
O	RF	300.1	178.1	381.9	50.3	154.8	147.5	166.5	299.8	273.2	365.1	289.9	267.9	292.2	174.2	204.5		240.2	292.7	285	244	472.5	351.2	185
	Qt	108	64.1	137.5	18.1	55.7	53.1	59.9	107.9	98.4	131.4	104.4	96.4	105.2	62.7	73.6		86.5	105.4	102.6	87.8	170.1	126.4	66.6
	Vt	400	197.6	194.8	83.3	22.8	65.6	11.4	339	339.7	285.5	333.3	400	341.1	184.5	382		392.3	400	377.4	283.6	271.3	290.3	123.8
N	RF	120.1	12.9	42.4	29.8	4.4	106.1	67.1	39.9	23.3	14.2	33.7	39.2	35.6	108.1	43		124.7	5.6	15.6	58.8	97.8	49	82.6
	Qt	43.2	4.6	15.3	10.7	1.6	38.2	24.2	14.4	8.4	5.1	12.1	14.1	12.8	38.9	15.5		44.9	2	5.6	21.2	35.2	17.6	29.7
	Vt	366.3	225.3	144.2	28.1	0	37.9	0	287.5	282.3	224.7	279.5	348.2	288.1	157.5	331.7		371.4	336.1	317.2	238.9	240.6	242	87.6
D	RF	14.7	1.1	20	22.8	2.5	50	30.2	28.5	58.6	25.1	68.6	11.9	16.1	48.6	21.8		9.1	1.1	2.1	42	9.4	48.7	3.9
	Qt	5.3	0.4	7.2	8.2	0.9	18	10.9	10.3	21.1	9	24.7	4.3	5.8	17.5	7.8		3.3	0.4	0.8	15.1	3.4	17.5	1.4
	Vt	305.7	159.9	85.5	0	0	0	0	231.9	237.5	167.8	238.4	286.6	227.9	109.1	273.6		308.8	270.6	252.1	188.2	178.1	193.7	23.1

RF is rainfall in mm, Q_t (m^3), V_t (m^3)

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Table III. Summary of reliability values for varied roof and storage tank sizes

Storage tank size(m^3)	$300m^2$ roof area		$400m^2$ roof area		
	Failure months	Reliability (%)	Total simulation months	Failure months	Reliability (%)
60	-	-	264	125	53
90	157	41	264	-	-
100	155	41.3	264	107	60
200	144	46	264	67	75
300	144	46	264	51	81
400	144	46	264	37	86

Table IV: harvesting potential for roof size of $400m^2$

Months	mean monthly rainfall (m^3)	Monthly harvestable rainwater(m^3)	Cumulative harvested rainwater(m^3)	Monthly water demand (m^3)	Cumulative demand (m^3)	Difference between 4 and 6(excess /deficit)
January	21.5	7.7	7.7	65.88	65.88	-58.2
February	44.5	16	23.7	65.88	131.8	-108.1
March	102.7	36.97	60.7	65.88	197.6	-136.9
April	170	61.2	121.9	65.88	263.5	-141.6
May	210.5	75.8	197.7	65.88	329.4	-131.7
June	245.5	88.4	286.1	65.88	395.3	-109.2
July	317.1	114.2	400.3	65.88	461.2	-60.9
August	307.8	110.8	511.1	65.88	527	-15.9
September	319.9	115.2	626.3	65.88	592.9	33.9
October	255.3	91.9	718.2	65.88	658.8	59.4
November	52.5	18.9	737.1	65.88	724.7	12.4
December	24.4	8.8	745.9	65.88	790.6	-44.7

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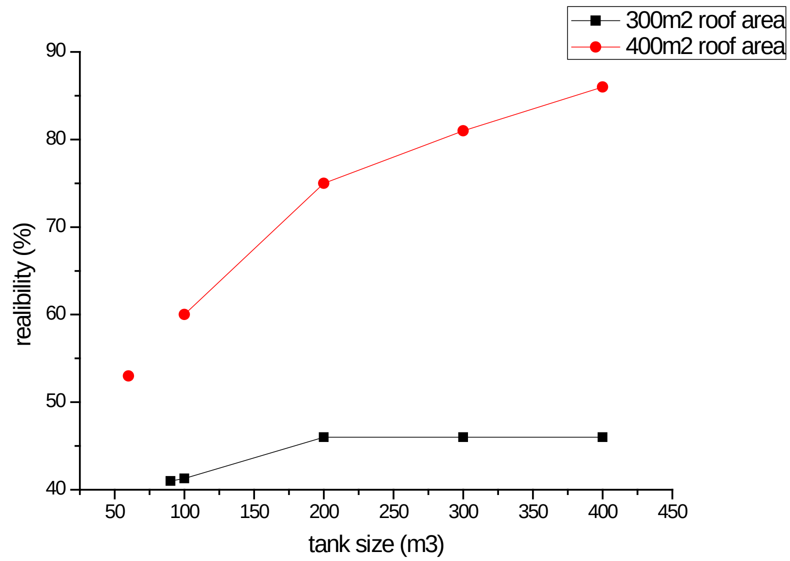


Fig 2.reliabilty curves for varied roof and tank sizes at the demand of 65.880m^3

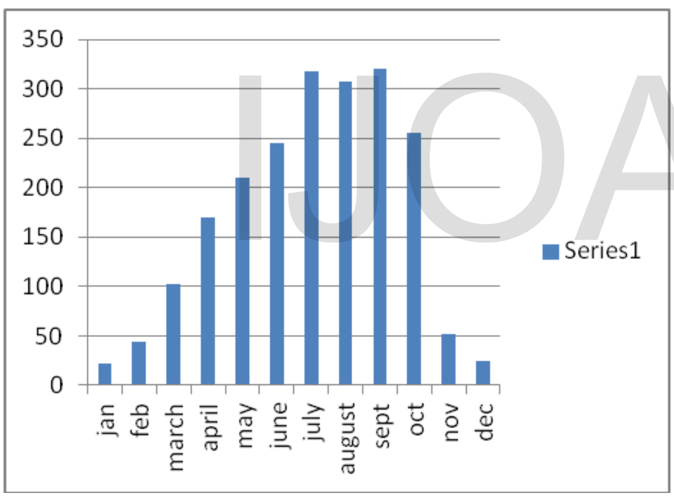


Fig 1. Mean monthly Rainfall time series (mm) from (1980-2002)

4.1 green roof and flood control

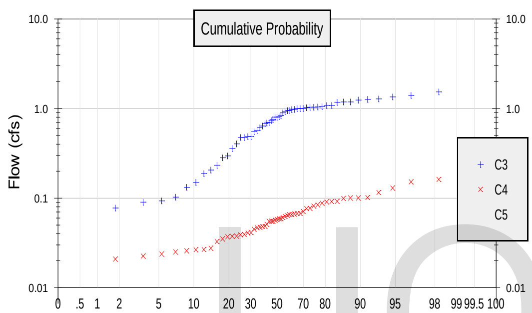
Green roofs are techniques for capturing rain water which generally consist of a membrane and drainage layer topped with a soil like growing medium and hardy plants. Amongst the numerous benefits obtained from its application, its ability and relevance in reducing significantly runoff peak of the most rain fall events is recognized, this it achieves by delaying the initial time of runoff due to water absorption in the roof system, reducing total runoff by retaining part of the rainfall, and distributing the runoff over a long time period via a relative slow release of excess water stored in the pores of the substrate temporarily, i.e. reducing the frequency of flow. Reducing frequency flow of rainfall events especially high intensity rainfall events contributes significantly to flood reduction. The tables below reflects the effect of green roof on frequency flow. For this case, $400m^2$(~0.25 acre) roof area represents 10% of total catchment area usually recommended for green roof application.it is clear from the table that flow frequency from predeveloped to mitigated scenario for the simulated years show a steady reduction from the first 2 years down to the 100^{th} year having approximately 81% and 86% minimum and maximum reductions respectively, Plus (+ or blue) in the figure represents flow at predeveloped phase and (x or red) flow at mitigated phase. Reducing the frequency of flow at this rate, doubtless slows down storm water flow into drainage systems, which when captured and directed to a storage facility could serve for other domestic purpose. It is also clear from the tables of annual peaks, that there is a gradual and steady frequency flow reduction from the mid 1960 down to early 2000, most of which have a mitigated flow falling below 0cfs. About 82% of the simulated years had flow reduced to less than 0cfs (cubic feet/sec), achieving this degree of reduced flow speed enables control over storm runoff, hence contributing to flood reduction.

Table V. Summary of flow frequency reduction for green roof

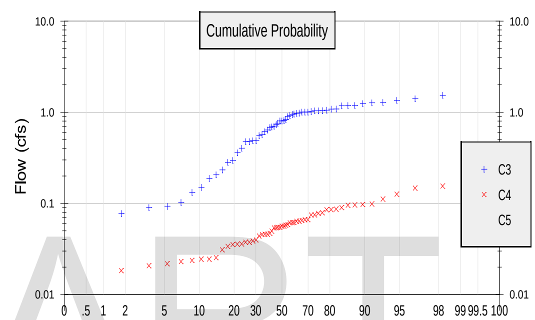
Flow (cfs)	Predeveloped	Mitigated	% reduction
2 years	3.2822	0.6159	81.2%
5years	6.2203	0.9250	85%
10 years	8.0401	1.1494	85.7%
25 years	10.0334	1.4539	85.5%
50 years	11.2808	1.6954	84.9%
100 years	12.3397	1.9494	84.2%

4.2 sensitivity analysis

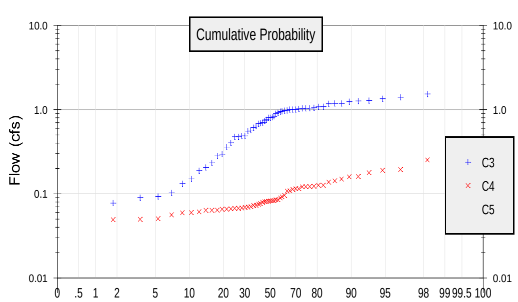
Green roofs contribute to flood control by slowing down or reducing the frequency of storm runoff. The response of green roof (0.25 acre) under shrubs and ground cover vegetation types, at various slopes (0.001-5) are reflected on the following figures below. A slightly improved flow frequency reduction from the predeveloped to the mitigated is observable on the shrub vegetation type over the ground cover type vegetation, this is however marginal (0.3% on the first 2 years) while the range for the entire simulated period is about (0.2-0.6%). Further still, it is clear from the figures of 3a to 3i that the steeper the green roof slope, the lesser the reduced frequency flow i.e. the faster the flow hence creating a vulnerable flooding situation, thus implying an inverse relationship. The green roof slope of 0.001 gives the highest flow frequency reduction of approx. 94% while the slope of 5 is 77% .These results are consistent with [5] who reported steeper roofs as harvesting more water. Thus a less steep green roof is preferred, in this case 0.001 slope for flood control. Again, it is also clear that a gradual and steady increase in frequency flow reduction is observed from the beginning down to the end of the simulation period for all slope range examined on both shrub and ground cover vegetation types. About 0.2-1.2% on the 0.001 slope for he ground cover vegetation, and 0.1-3% on the shrub vegetation and 0.001 slope. From the figures, its yet clear that above a slope of 0.1 the mitigated flow begins to bypass the predeveloped flow, indicating the commencement of a possible contribution to flooding or logging, rather than controlling it (i.e. mitigated flow approaching or closing up on predeveloped flow. Note, entire purpose on flow frequency reduction to control flooding is for the mitigated peaks to be as far away or lower from predeveloped as possible).



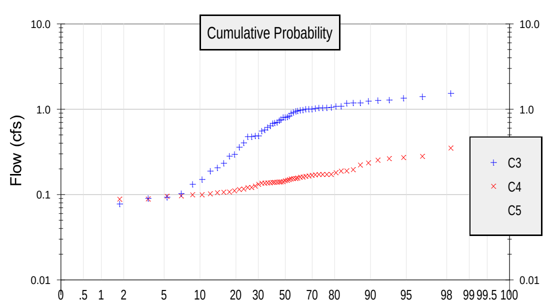
(a)ground cover at 0.001 slope



(b)shrub at 0.001 slope



(c)shrub at 0.01 slope



(d)shrub at 0.1 slope

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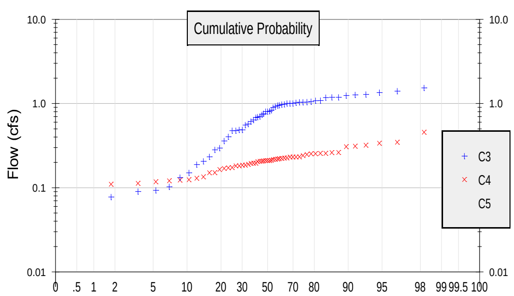
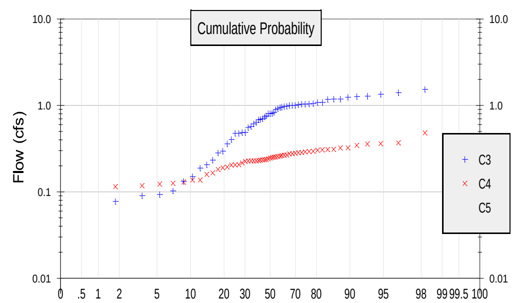
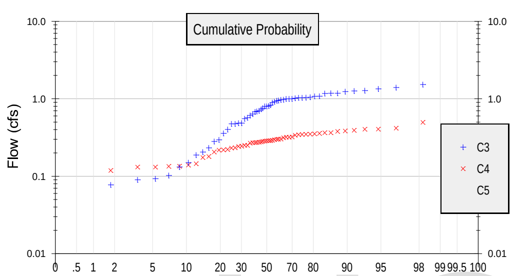


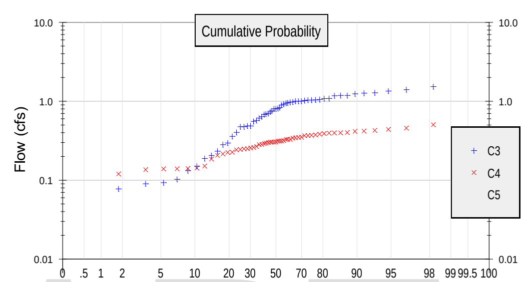
(e) Shrub at 0.5 slope



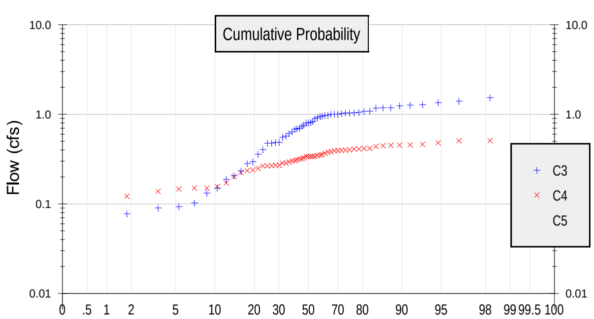
(f)shrub at slope 1



(g) shrub at slope 2



(h)shrub at slope 3



(i)shrub at slope 5

Figures 3(a-i) green roof response to varied slopes and vegetation types. y-axis is flow frequency in cfs and x-axis is time in years

5.0 Conclusion

This study examined and emphasized its dual role for water supply and flood (using green roof) control, for Benin City Nigeria as case study. Green roof is an eco-friendly mode of harvesting rain water having an additional aesthetic value and cost advantage over other ecofriendly methods. A green roof catchment area and storage tank size of $400m^2$ and $400m^3$ were determined respectively as appropriate for the high demand scenario (high buildings) .a reliability of 86% was attained for this storage tank size, as this ensured less failure months of harvested water for water supply. Benin City has a high annual harvesting potential of 745.9m3, and green roof with shrub vegetation type could reduce the flow frequency on a 1 acre land basin by over 90%, which is significant in flood control. Sensitivity analysis indicate a less steep green roof with shrub vegetation contributes significantly to flow frequency reduction hence flood reduction. Generally, the practice of green roofs in Nigeria is rare. This paper therefore would find usefulness for policy makers, urban planners, engineers, and the public water consumers and also help to add to the body of knowledge existing in this field.

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