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Calibration of Rainfall-Rainwater Capturing Mechanism Using Integrated Water Management Model (IWM_m) in Auchi, Nigeria

Accessibility of safe drinking water is a serious constraint in Auchi and its environs. This region mainly depends on rainwater and groundwater exploration. Sensitivity simulation analysis using structured IWRM *model shows that there is a strong relationship with the rainfall, rainwater capture and roof plan size* (RPS). *Average annual rainfall of 1430 mm and 1600 mm simulated with varying roof plan surfaces (RPS) of* 100 m^2*,* 250 m^2; 500 m^2; 1000 m^2; *and* 2000 m^2 *produced* RWHI *index of 0.1, 0.24, 0.47, 0.94 and 1.89 respectively. Simulation output indicated that an average of 5,300m^3 /day of rainwater were harvestable and this value of water could only meet daily water demand of 40,769 people. The output of statistics metrics shows a perfect match* (RPS) *and harvested rainwater as R^2= 0.78; 0.77 and r.m.s of 0.100 respectively. The overall result shows that if the potential of rainwater harvest is fully-harnessed, that will reduce the water stress and constrain in Auchi.*

Keywords: *Simulation, Rainwater, Rainfall, Model, RWHI, IWRM, RPS, Output*

1. Introduction

Water is an essential and precious resources upon which our land and agricultural production depends on. However, water is a transparent fluid which forms the world stream, lakes, and ocean and rain and a major constituent of living things (Hegen, 2012). Water molecules consist of hydrogen and oxygen (H_2O)(Jenkin,1999). This constitutes 1.384 million cubic kilometer of which around 97.39% is the ocean, another 2.61% is fresh water only small fraction of about 0.59% of the total water is present in the ground, lake, river and atmosphere and it is useful to mankind (Dixon, 1999).

Water scarcity is a characteristic of Edo North. The scarcity in Edo North is increasing; and this continues to aggravate the water-stress situation. The exponential distribution and increase in population and subsequent urbanization in Edo-North has caused a major strain on water ways. The alternate mean of accessing water is through rain-harvesting system which is predominant in the region (Olotu et al., 2013). Water supply and distribution system have typical been as an economic problem rather than engineering problem (Latham, 2000). Water supply manager and stakeholders are of terms that apply price increase as water conservation tools instead of relying on price demand management technology (Idogho et al., 2003). The problem of water withdrawing from the ground as been categorized as high technical-tech system (McMahon, 2008). It requires highly experienced drillers and engineers and the overall operation is capital intensive. Water is a bulky commodity: its par unit value is low, making the cost of transportation and storage high relative to its overall value in use with growing population and limited resources there is an increasing need to manage water in Auchi, Nigeria.

Having considered the complex situation being faced with water availability, accessibility and coverage in this region; alternative water source such as rainwater and underground water will be subjected to simulation analysis using IWRM models to determine and project supplementary potential of water supply and distribution in order to create a stochastically-based management mechanics useful in proffering realistic measures of resolving acute water shortage in the affected region.

2. Materials and Methods

2.1 Description of the study area

Edo north comprises of various villages and town and it contains 6 (six) local government area which are Akoko Edo, Etsako East, Etsako West, Etsako Central, Owan East and Owan West. The most water stressed area is the Etsako West local government which include Auchi, Jattu, South Ibie (Olotu et al., 2013). Etsako west local government area was created in 1991 it lies between the northern latitude of 7,066′7 (74′0.012N) and to the east longitude of 6,2667 (616;0.012E). The average annual rainfall of Auchi is 1300mm with a bimodial distribution. The first peak occurs in October. Auchi is densely populated due to the influx of people in and out of the place as a result of its strong commercial and education links (Idogho et al., 2013). In addition, Edo state has approximately between latitude 05^0 44N and 07^0 34N of the equator and between latitude 06^0 04E and $06^0$43E. It is bounded in the south by Delta state in the west by Ondo state in the north by Kogi state and in the east by Anambra state. According to 2006 national census, Etsako west has population of 1277,718 which comprises of 65,312 male and 62,406 female. The soil type is reddish yellow in colour. The map of the region is shown in fig.1.

Plate 1. Satellite Image for Auchi

2.2. Model description

IWRM model applies some concepts of Behavioural models to investigate, calibrate and validate the storage mechanism of rainwater for optimal usage. The yield after spillage would only be considered for running IWRM model as follows:

$$Y_{sp} = \quad [Is]_t \quad hour \quad (\quad [Q_{r+1} \qquad (1)$$

$$Q_r = \quad [0.85R_d*A\,] \quad hour \quad (\quad (S_m - Q_r \qquad (2)$$

Where: I_s = Initial storage (m^3), Y_{sp} = Yield after spillage (m^3)
R_d = Rainfall (mm), S = Store Capacity (m^3), A = Roof Area (m^2)

The potential yield from rain water is a function of the roof size, roof type and fitter efficiency. The potential yield of rain water and rainfall relationship for various roof materials such as steel, asbestos and concrete roofs as follows (Olotu et al., 2013):

$$P_{ys}= 0.85R_f \quad (3)$$

$$P_{ya}= 0.82R_f \quad (4)$$

$$P_{yc} = 0.75R_f \quad (5)$$

P_{ys}, P_{ya} and P_{yc} are the potential rainwater yield from the steel, asbestos and concrete roofs respectively. R_f is the rainfall in mm. Roof catchment factor for steel, asbestos and concrete are 0.85, 0.82 and 0.75 respectively. The potential yield of rainwater harvesting is modeled as follow:

$$R_{wh} = \alpha NRp \quad (6)$$

Where: Rwh = Rainfall harvest (mm), Rp= Roof plan size (m^2)
α = Fitter efficiency, N = Collection efficiency

2.2.1. Data analysis

The output of the simulation was analysed using the logarithm, power and linear analytical iteration of excel 2013 version. Validation statistic such as coefficient of determination and root mean square were used to compare to results.

3.1. Results and discussion

3.1.1. Rainfall and rainwater collection

Table 1-5 show results of annual rainfall and harvested rainwater in some selected location within and around the study area over a period of 13 years (1999-2008). The results describe significance the relationship of roof plan sizes and volume of harvestable rainfall-rainwater collection. Average highest total rainwater of ($1.6m^3*10^2$) was captured using roof plan size ($100m^2$) with an average rainfall depth value of 1,660mm, while highest volume of rainwater ($31.2\ m^3*10^3$) was collected with roof plan size ($2000\ m^2$) and rainfall depth of 1,660 mm respectively. Analysis of harvestable rainwater from selected regions indicated that only ($5.3*10^2m^3$) of water could be captured on annual basis as shown in table 7.

Table 1. Annual average rainfall and pottential rain water collection in Auchi RPS ($100M^2$)

S/N	Year	RAINFALL (mm)*10^3	RWC (m^3)*10^2	RAIN WATER HARVEST INDEX
1	1996	1.43	1.3	0.09
2	1997	1.49	1.4	0.09
3	1998	1.51	1.4	0.10
4	1999	1.45	1.4	0.10
5	2000	1.50	1.4	0.10
6	2001	1.49	1.4	0.10
7	2002	1.51	1.4	0.10
8	2003	1,53	1.5	0.10
9	2004	1.58	1.5	0.10
10	2005	1.56	1.5	0.10

11	2006	1.56	1.5	0.10
12	2007	1.56	1.5	0.10
13	2008	1.56	1.6	0.10

Source: Simulation output, 2015

Table 2. Annual average rainfall and pottential rainwater collection in Auchi RPS (250M^2)

S/N	YEAR	RAINFALL (mm)*10^3	RWC (m^3)*10^2	RAIN WATER HARVEST INDEX
1	1996	1.43	3.4	0.24
2	1997	1.49	3.5	0.24
3	1998	1.51	3.5	0.24
4	1999	1.45	3.4	0.24
5	2000	1.50	3.5	0.24
6	2001	1.49	3.5	0.24
7	2002	1.51	3.5	0.24
8	2003	1.53	3.6	0.24
9	2004	1.58	3.7	0.24
10	2005	1.56	3.7	0.24
11	2006	1.56	3.7	0.24
12	2007	1.56	3.7	0.24
13	2008	1.66	3.9	0.24

Source: Simulation output, 2015

Table 3. Annual average rainfall and pottential rainwater collection in Auchi (500 M^2)

S/N	YEAR	RAINFALL (mm)*10^3	RWC (m^2)* 10^2	RAINWATER HARVEST INDEX
1	1996	1.43	6.7	0.46
2	1997	1.49	7.0	0.46
3	1998	1.51	7.2	0.47
4	1999	1.45	7.1	0.49
5	2000	1.50	7.1	0.48
6	2001	1.49	7.0	0.46
7	2002	1.51	7.1	0.47
8	2003	1.53	7.2	0.47
9	2004	1.56	7.4	0.47
10	2005	1.56	7.4	0.48
11	2006	1.56	7.3	0.47
12	2007	1.56	7.3	0.47
13	2008	1.66	7.8	0.47

Source: Simulation output, 2015

Table 4. Annual average rainfall and pottential rainwater collection Auchi roof plan size (1000m^2)

S/N	YEAR	RAINFALL (mm)*10	RWC(m^2)*10^2	RAINWATER HARVEST INDEX
1	1996	1.43	13.4	0.94
2	1997	1.49	14.0	0.94

3	1998	1.51	14.2	0.94
4	1999	1.45	13.7	0.95
5	2000	1.50	14.2	0.95
6	2001	1.49	14.0	0.94
7	2002	1.51	14.2	0.94
8	2003	1.53	14.4	0.95
9	2004	1.58	14.8	0.94
10	2005	1.56	14.8	0.95
11	2006	1.56	14.6	0.94
12	2007	1.56	14.6	0.94
13	2008	1.66	14.6	0.94

Source: Simulation output, 2015

Table 5. Annual average rainfall and pottential rainwater collection Auchi roof plan size (2000m^2)

S/N	YEAR	RAINFALL (mm)×10^3	RWC (m^2)×10^2	RAINWATER HARVEST IDEX
1	1996	1.43	26.9	1.89
2	1997	1.49	28.1	1.89
3	1998	1.51	28.5	1.89
4	1999	1.45	28.4	1.89
5	2000	1.50	28.5	1.89
6	2001	1.49	28.0	1.89
7	2002	1.51	28.5	1.89
8	2003	1.53	28.8	1.89
9	2004	1.58	29.6	1.89
10	2005	1.56	29.6	1.89
11	2006	1.56	27.2	1.89
12	2007	1.56	27.2	1.75
13	2008	1.66	31.2	1.75

Source: Simulation output, 2015

Table 6. Cumulative average daily potential rainwater collection (m^3) in Auchi

Nr.crt.	Year	Rainwater collection (m^{3}10^3)
1	1996	5.2
2	1997	5.3
3	1998	5.3
4	1999	5.3
5	2000	5.3
6	2001	5.3
7	2002	5.3
8	2003	5.3
9	2004	5.4
10	2005	5.6

11	2006	5.2
12	2007	5.5
13	2008	5.5

Source: Simulation output, 2015

Water resource data and statistics are often provided on a per capital basis. This represents an average across the entire population, giving the impression of equality in the availability of the utility. The calibration result in figure.5 and 6 show the relationship between rainwater collections (***RW***) and roof plans (***RPS***) as outputs. Strong relationship exists between average water collection and surface area or roof area of collection with ***R^2=0.7851, R^2=7727 and R^2=0.772*** for polynomial, logarithm and power of the excel 2013 version under the RPS (100m^2) respectively***.*** The output iteration for analysis for the RPS 250m^2, 500m^2, 1000m^2 and 2000m^2 showed the same trend analytical output with 100m^2 RPS from the tested statistics metrics. The R^2 of 1.00 shows a perfect match. In addition, magnitude of annual rainfall depth is a strong indicator influencing the volume of rainwater collection. Again, there is no strong connection between the volumes of water captured and period of harvest as indicated in figure 7.

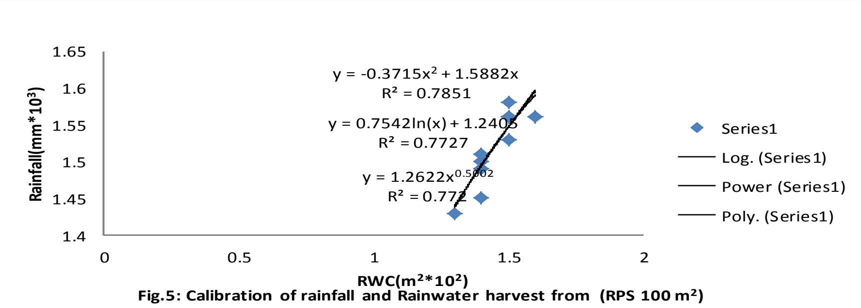

Fig.5: Calibration of rainfall and Rainwater harvest from (RPS 100 m^2)

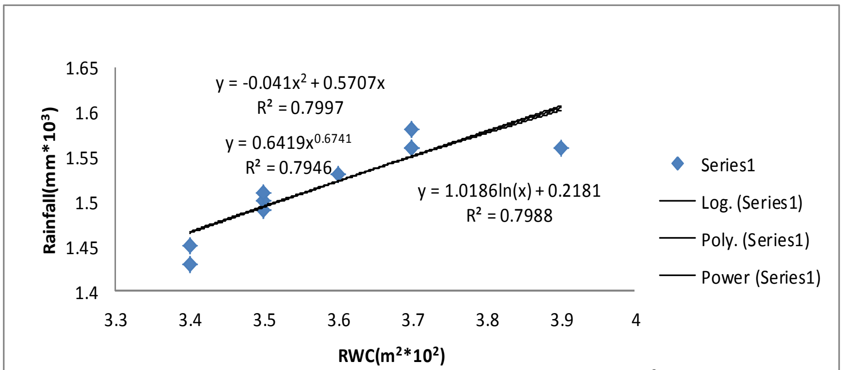

Fig.6:Calibration of rainfall and rainwater harvest from RPS 250 m^2)

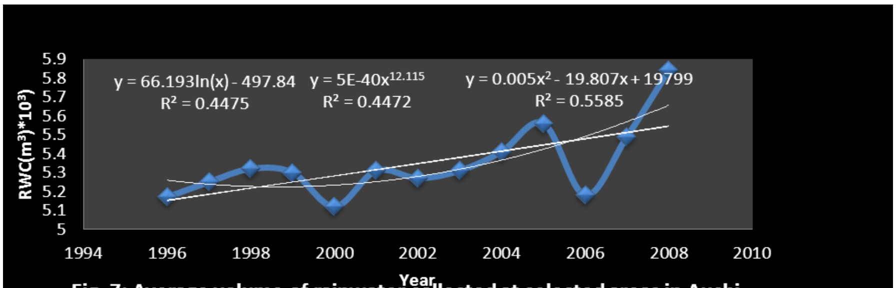

Fig. 7: Average volume of rainwater collected at selected areas in Auchi

4. Conclusion

Steady increase in world's population is responsible for the pressure on the demand for safe drinking water. Meeting the increasing demand for the limited utility, alternative water sources of rainwater harvesting is considered. The overall analysis using different statistics metrics show rainwater harvesting system indicated that only 12.8% of total water demand could be achieved from this source.

As a result of this, most of the harvested rainwater spilled off the storage tank and becomes unavailable for both potable and non-potable applications. The potential benefits of rainwater harvesting are not widely appreciated and this should be addressed through an educational and technological advancement programme. The rainfall catchment areas and storage tank must be designed and simulated for maximum possible rainwater runoff as shown with the *RWHI* of 0.1, 0.24, 0.47, 0.94 and 1.85 for RPS of 100m^2, 250m2, 500m^2, 1000m^2 and 2000m^2 respectively.

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