

URBAN STORM WATER DRAINAGE SYSTEMS MODELING FOR OBUBRA CENTRAL SENATORIAL DISTRICT, CROSS RIVER STATE OF NIGERIA.

Obio¹, E. A, Ahaneku², I.E., Onwuka³, U.N.

¹Department of Agronomy, University of Cross River State, Calabar. ekpeobio2016@gmail.com

²Department of Agricultural and Bio resources Engineering,

³Department of Agricultural Michael Okpara University of Agriculture, Umidike, Abia State.

Accepted: 20th October, 2023

Review: 27th October, 2023

Approved: 6th December, 2023

ABSTRACT

The modeling of storm water drainage systems of Obura catchment area of Cross River State, Nigeria to address problem of local flooding. A current metre was used alongside a speed boat to carry out measurement of discharge as a dependable variable while cross sectional area, velocity, width and depth of channel was also determined as independent variables. The data so measured were subjected to developed a model whose result was $Q = -2417.75 + 11.68D + 0.33W + 1772.15V + 1.24A$. The model gave a correlation r value of 0.994. Verification of the model was carried out and an r value of 0.995 was obtained all indicating a strong correlation. Furthermore, a validation test was conducted using velocity-area method for water flow measurement having a relationship as $Q = AV$, a correlation value of 1.0 The study recommends that, proper design, computations, adequate constitutions and routine maintenance of drainage channels be made ensuring that the velocity satisfied the minimum requirement.

Keywords: Drainage, Urbanization, Storm water, Molding, Catchment, Flooding.

Introduction

Water is the common natural resource and necessary for all living things. However, the present situation of water quality management in the world is not acceptable, mainly due to the forces of increasing population and economic development.

Drainage systems are needed in urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from water bodies to provide water supply for human life, and the covering of land with

impermeable materials to divert rainwater away from the local natural system of drainage. These two types of interaction give rise to two types of water that requires drainage (Butler and Davies, 2004). Waste water is water that has been supplied to maintain standard of living and satisfy the needs of industry after use, if not drained properly, it could cause pollution and create health risks. Wastewater contains, fine solids and large solids originating from water closet (WCs), from washing of various sorts, from industry and other water uses.

Urban drainage system handles these two types of water with the aim of minimizing the problems caused to human life and the environment.

Urban drainage has two major interfaces with the public and the environment.

countries with substantial urban infrastructure in place. The magnitude of investment required to construct, operate and maintain urban storm drainage acidities and the potential for significant adverse social and environmental impacts mandate the use of the best possible methods of planning, analysis and design.

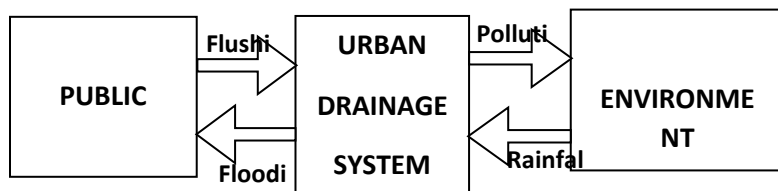


Fig 1.1 Interfaces with the public and the environment

Urban drainage defines the systems which have been designed to drain wastewater and stormwater out of populated areas. However, drainage is necessary to handle wastewater generated by populations and stormwater generated by rain events. Thus, Urban drainage is at the interface between populations (public) and their environment as presented in figure 1.1. It shows already how complex it can be to keep a certain balance between the different processes. The population and industry consume water and flush wastewater to the system which in the same time might receive stormwater. Part of the wastewater and of the stormwater is treated depending on the System capacity. The rest of it overflows to the receiving waters. Flooding can be generated at different steps of the process.

The increase in population density and building exert the most obvious influence on hydrological process in an urban area. Modification of the land surface during urbanization alters the storm water runoff characteristics. The major modifications which alter the runoff processes is the impervious surface of the catchment such as roofs, sidewalks, roadways and parking lots, which were previously pervious.

The urban water system is a complex structure consisting of drinking water production from a new water source (surface or underground) distribution of water to consumers in a pipe system, urban drainage (i.e conveyance of wastewater and storm water) and in the end treatment of the wastewater and discharge to receiving waters.

Storm water drainage has become a central issue in urban planning and management particularly in developed

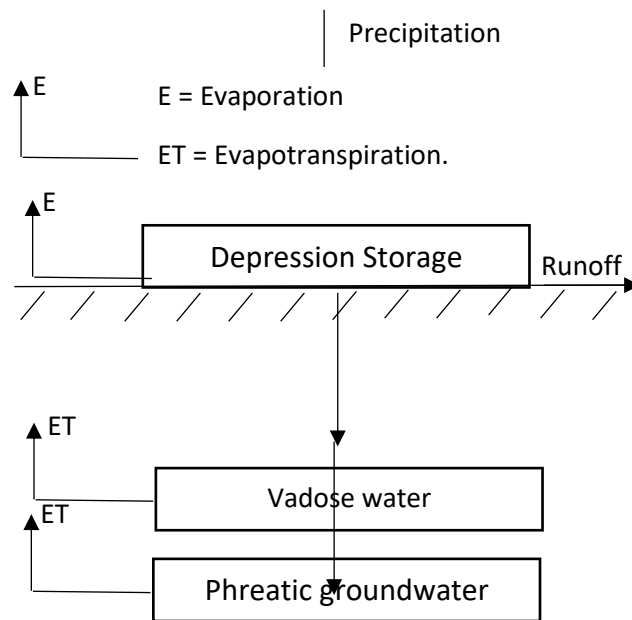


Fig. 2.1 Rainfall-runoff Components of hydrological Cycle

MATERIALS AND METHOD

The study area is located in the Central Senatorial District of Cross River State, Nigeria. The state is bounded in the North by Benue State, in the West by Ebonyi and Abia States, South West by Akwa Ibom State and the Cameroon Republic in the East. Obubra is a Local Government Area of Cross River State, Nigeria. It's headquarters are in the town of Obubra which is home to the National Youth Service Corps Orientation Camp. It has an area of 1115km² and lies between latitude 6° 5'N of the equator and longitude 8° 18' E within the rainforest zone of south-south Nigeria. It has a population of 172,549 based on the 2006 census.

The mean annual rainfall of the study area is 2250-3000mm per annum and a mean annual temperature of between 21°C-29°C (CRADP, 1992). The soil type of the area is predominantly sandy loam with an undulating topography with a slight slope. The area receives about 90% of the total annual rainfall during the period. It is however usually disrupted by a short dry season in August (August Break).

The area consists of the rainforest belt of Nigeria whose primary vegetation has however been replaced by the secondary forest. In some of the parts of the area, the savannah type grassland emerges during the hamarttan season after the seasonal fires. The forests have therefore been continuously given way farms residential and infrastructural developments. The people of the area are mostly farmers and traders. They main crops cultivated are yam, maize, melon, cassava, sweet potatoes, cocoyam and Vegetables. The land is being Use for residential and industrial purposes. It is expected that there will be an increasing need for industrial use of the rivers based on the development programs that are being put in place by state government and others.

The geology of Cross River State is characterized by the underlying Eze Aku Shale group of black shale and silt stone. The soils are generally shallow, well drained and stony.

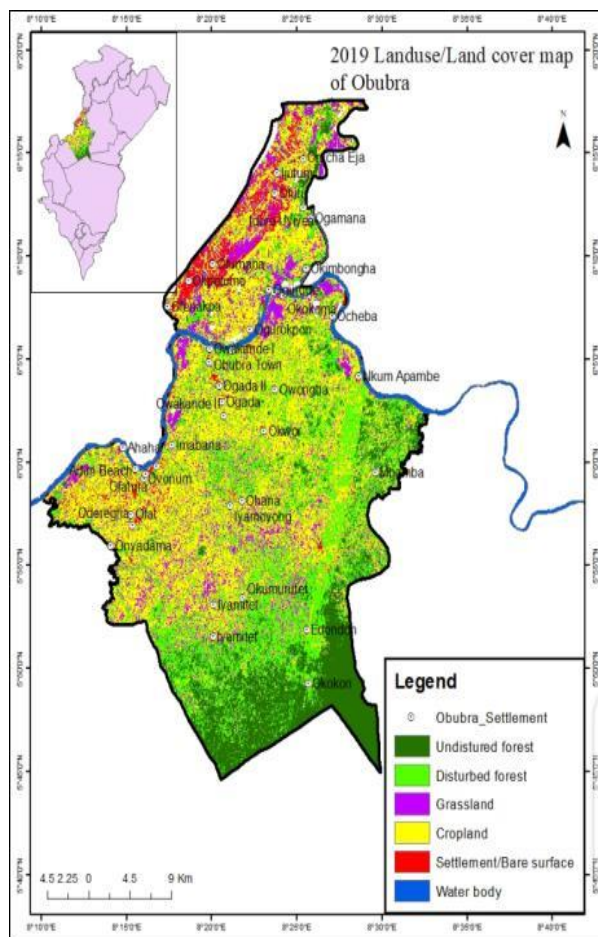


Figure 3.1 Map of study area.

A. 3.1 Rainfall Measurements

Rainfall measurements for the data at the Cross River Basin Development Authority (CRBDA) and Cross River University of Technology, Obubra Campus, Cross River State. Two sets of rainfall data were obtained for the study. The first was a twenty-four (24) months daily rainfall data, while the second was a thirty-six (36) yearly / monthly rainfall data from 1979 to 2014

3.2 Land use data.

This was obtained from the most recent use topo map (2011) of the study area obtained from the state ministry of Land and Survey, Calabar. The Land Development Software was engaged with the application of the poly-line approach in discretizing both the total basin area and the area that has become built-up (Okon, 2012)

3.3 Slope of the catchment.

The topographical map with the aid of the Land Development Software was used to generate the Sub-Catchment of the area the profiling approach was equally employed for confirmation. The study area was divided into regular grids of 25m by 25m square. Stakes wheredriven at the corners of the grids and a dumpy level is used to determine the elevation of the corners. Points with equal elevation were joined to produce a contour map. With the contour map, the slope was computed from the expression:

$$G = \frac{\Delta y}{\Delta x}$$

Where Δy = change in height between the first and the last contour.

Δx = corresponding horizontal distance.

A Global Positioning System (G.P.S.) instrument was used; mapping was carried out by marking of 25m interval on ground. The entire length of the flow was covered within the sub-drainage basins. The plot of the inlet and outlet elevations was obtained to the overland flow length. The tangent of the angle formed gave the value of the slope (Uyanah 2006, Okon. 2012).

3.4 Model Development

Mulligan and Wainwright (2004) identified three (3) purpose among others to which a general model is usually put. They include;

- An aid to research
- As a tool for simulation and prediction
- As a research product

However, to effectively execute the objectives of this study, different approaches were employed to develop a model with the right result to serve as a tool

for the analysis of storm water drainage of Obubra catchment. The approaches were the multiple Regression approach and the Marko chain approach.

Brezonik and Staidelmann (2002) observed that storm water models are usually based on regression analysis between water quantity, quality and relevant explanatory variables. Empirical models describe the observed behaviour between variables using the observations alone and do not include any process.

In terms of storm water modelling, an empirical approach would be a model that relates runoff quantity to a number of factors such as rainfall or other characteristics of the catchment as discussed.

RESULT AND DISCUSSION

4.1 MODEL VARIABLES

The model variables are Q, A, W, V and D.

Where Q = Discharge (m^3/s)

A = Cross Sectional area (m^2)

W = Width of channel (m)

V = Velocity of channel flow (m/s)

D = Depth of channel (m)

4.2 ASSUMPTIONS

$$Q = 0, \text{ if } A \leq 0 \text{ or } = 0$$

$$Q = 0, \text{ if } V \leq 0 \text{ or } = 0$$

$$Q = 0, \text{ if } D \leq 0 \text{ or } = 0$$

$$Q = 0, \text{ if } W \leq 0 \text{ or } = 0$$

Q is not equal to 0, if and only if the values of A, V, D and W are ≥ 0

values of 20 data set were selected from the total as represented in appendix 1 to carry out the modeling of storm water drainage of Obubra catchment. The first ten (10) data was used for calibration of the model and the last ten (10) for verification of the model.

Table 4.1 Relationship between depth, width, velocity, area

and discharges.

	Depth (m)	Width	Velocity	Area	Measured Discharge (Q)	<i>Predicted Discharge (Q)</i>
1	4.5	362.33	1.992	1630.485	3247.926	3306.303
2	3.7	501.12	1.676	1854.144	3107.545	3060.098
3	5.3	467.61	1.050	2478.333	2602.250	2732.356
4	4.1	352.06	1.652	1443.446	2384.573	2463.783
5	5.7	272.47	1.454	1553.079	2258.177	2241.265
6	5.7	356.50	1.023	2032.050	2078.787	2099.122
7	5.7	356.50	1.020	2032.050	2072.691	2093.806
8	5.7	356.50	1.008	2032.050	2048.306	2072.540
9	3.3	578.10	1.045	1907.730	1993.578	2029.049
10	3.7	501.12	1.050	1854.144	1946.851	1950.732
11	5.3	325.72	1.104	1726.316	1905.853	1848.727
12	2.9	523.23	1.231	1517.367	1867.879	1851.840
13	3.7	501.12	1.900	1854.144	3522.874	3457.059
14	2.9	362.33	1.565	1050.757	1644.435	1812.044
15	3.3	585.05	1.800	1930.665	3475.197	3397.755
16	4.5	347.24	1.020	1562.580	1593.832	1494.591
17	3.7	346.72	1.211	1282.864	1553.548	1476.709
18	4.1	494.24	1.600	2026.384	3242.214	3141.393
19	3.7	342.06	1.104	1265.622	1397.247	1264.171
20	1.7	578.10	1.331	982.770	1308.067	1370.245

Table 4.1 below represent the relationship of they variables as was measured during transit in the river. The

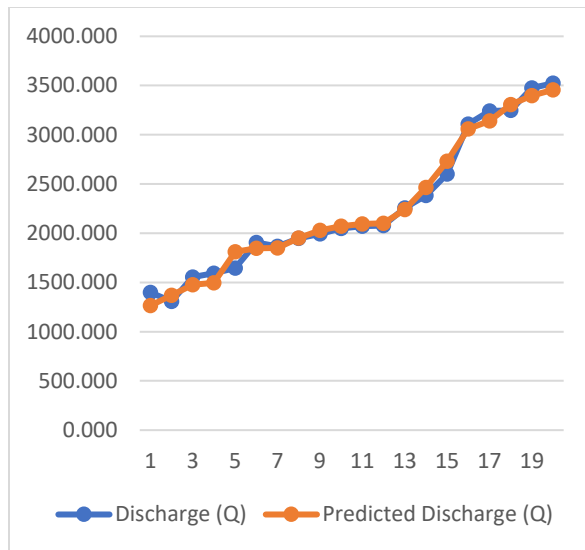


Fig 4.1 Measured and predicted plot of the model

Table 4.2 below shows the Pearson correlation for measured and predicted discharges represented by x and y respectively. It indicates the product of x and y, the square of x and y.

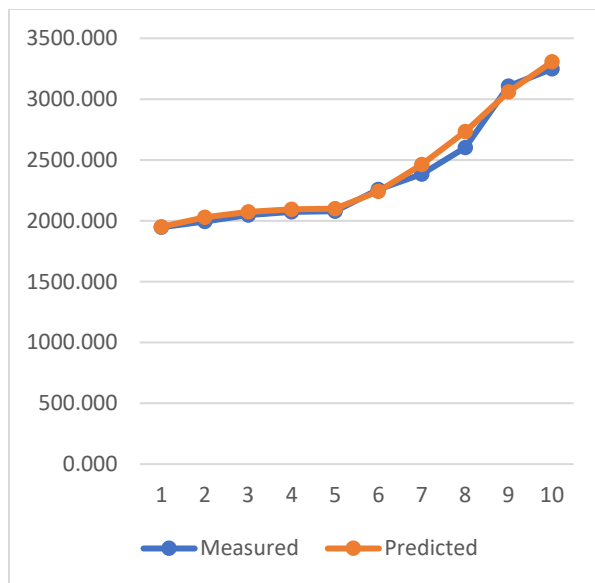


Fig 4.2. Plot showing model calibration

Table 4.4. Relationship between measured and predicted discharges for verification of the model.

X	Y	xy	x ²	y ²
1905.85	1848.72704	3523401.724	3632275.14	3417791.67

1867.88	1851.83963	3459011.943	3488971.13	3429310.02
3522.87	3457.05916	1217878.245	1241063.840	1195125.804
1644.43	1812.04433	2979788.583	2704165.50	3283504.65
3475.2	3397.7551	1180786.833	1207699.419	1154473.972
1593.83	1494.5914	2382127.002	2540299.17	2233803.45
1553.55	1476.70861	2294138.157	2413512.33	2180668.32
3242.21	3141.39336	1018507.079	1051195.422	9868352.24
1397.25	1264.17068	1766358.296	1952298.31	1598127.51
1308.07	1370.24545	1792372.677	1711038.94	1877572.59
21511.14	21114.53	52368919.65	53442147.32	51385128.21

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

$$r = \frac{10(52368919.65) - (21511.14)(21114.53)}{\sqrt{[10(53442147.32) - 462729350.95](10(51385128.21) - 462729350.95)}}$$

$$r = \frac{523689196.5 - 454197610.9}{\sqrt{4877050469404050}}$$

$$r = \frac{69491585.64}{69835882.39}$$

$$r = 0.995069916234791$$

$$r = 0.995$$

II. THE MODEL VALIDATION:

The model so developed was used to validate with the velocity-area method for water flow measurement having the relationship as $Q = AV$

Where Q = Discharge rate cm^3/s

A = cross-sectional area, cm^2

V = velocity of flow, cm/s

The method involves the flow of velocity of water passing a point in an open channels cross-sectional area of the flow at right angle to the direction of flow by the average velocity of water, since the float method and current meter are used to measure the velocity of water the discharge is determined by the equation $Q = AV$.

The values of the model were then used in the velocity-area method and the relationship of correlation of 1.0 was obtained showing a significant relationship of the model.

CONCLUSION AND RECOMMENDATIONS

Urbanization has been shown to increase surface runoff by creating more impervious surface such as pavement and structures that impede percolation thereby resulting to perennial flooding in some parts of the Obubra drainage basin which has been a thing of great concern to all residents in recent times. The volume of storm water runoff presents in any given point in time in an Urban watershed cannot be diminished or compressed. Runoff itself is a product of rainfall whose intensity exceeds the infiltration capacity of the soil.

While these events and many other globally, cannot be entirely mitigated, there is an intrinsic vulnerability to flooding associated with living in urban areas which is further exacerbated by increasing Urbanization and a changing climate. There is therefore a great need for a good knowledge of climate science as well as application of this knowledge to help adapt to changes being witnessed as well as curbing further changes. The Seasonal Rainfall Prediction (SRP) prepared yearly by the Nigerian Meteorological Agency (NIMET), is one of such tools that seek to bridge the gap between climate and human endeavor. Legislation against construction along the right-of-way of storm runoff and the provision of adequate drainage outlets is recommended in curbing the menace of flooding within the Obubra catchment. In addition, the use of empirical approach instead of the rule-of-thumb is also recommended in the design of the storm drainage systems in the area.

Stakeholders and Governments should as well increase their attempts in the construction of culverts, drainage channels and others water conveying or diversion structures to curb these flooded areas.

A redesign of inadequate drainage channels of basin is recommended to ensure that the drains are adequate enough to safely discharge the runoff generated.

The study also recommends that; proper design, computations (analysis), adequate constitution and routine maintenance of drainage channels be made ensuring that the velocity satisfies the minimum requirement.

III. REFERENCES

- Abam, T. K. S. (2004). Geohydrology with Applications to Environmental Management. Published in Nigeria by Charisma Graphics Aba Pp 39 – 60
- Adams, B. J. and Papa, F. (2000). Urban Storm Water Management Planning with analytical probabilistic
- Agunwamba, J. C. (2011). Water and waste management tools. Immaculate printers, Nigeria 24- 26
- Ahmad, N.B. (2008). Peak flow Attenuation using Dry Pond for existing Housing Scheme, Master Theses, University of Malaysia.
- Ahyerre, M., Chebbo, G., Tassin, B. and Gaume, E. (2008). Storm water quality modeling an ambitious objective? Water Science and Technology, 37(1), 205 – 213.
- Antigha E. E. (2015). Morphological studies of the Calabar Metropolis catchment South-South, Nigeria.
- Antigha E. E. (2015). Development of Rainfall Runoff Model for the Calabar Metropolis catchment using Differential Equation Approach.
- Antigha R, E.E., Akor, A.J. Ayotamuno, M.J. Ologhodien I, and Ogarekpe, N. M (2014). Rainfall – runoff Model for Calabar Metropolis using multiple regression, *Nigeria Journal of Technology*, 33(4), 566-573.

- Antigha R. E. E and Ogarekpe N. M (2013). Development of Intensity Duration Frequency curve for Calabar Metropolis, South-South Nigeria. International
- Antigha R. E. E. Ayotamuno, M. J. Fubara-Manual, I and Akor, A. J. (2015). Morphological studies of the Calabar Metropolis catchment, South-South Nigeria. *Journal of Environment Science Toxicology and Food Technology*. 9(6), 15-22
- Antigha, N. R. B. (2007). Infiltration characteristics of selected soils in Cross River State, Nigeria and their implication for sustainable crop production. Published Ph.D. Thesis in water Management and Soil conservation, University of Calabar, 3032.
- Brenzonik, P. L. and Stadelmann, T.H. (2002). Analysis and Predictive Model of Storm water runoff volumes, load and pollutant concentrations from watersheds in the Twin cities metropolitan area, Minnesota, U.S.A. In water Research 36(7): Pp 1743 – 57.
- Bridge, J. S. (2003) River and floodplains: forms, processes, and sedimentary record P.491 Malden, USA. Wiley- Blackwell.
- Bufill, M.C and Boyd, M.I (2002). “A simple flood Hydrograph model for urban catchment” International symposium on urban storm water management. Sydney Australia pp 88-103)
- Butler, D. and Davies, J.W. (2004). Urban Drainage, 2nd Edition. Spon Press. London.
- Butler, D. and Peter, K. (2002). Performance Indicators for Urban Storm drainages in developing countries, Urban water. Volume 4, issue 2, Pp 137-144.
- CA. 2007. Water for food, water for life. A comprehensive Assessment of water management in Agriculture D. molder (ed.) London, Earthscan and Colombo, International Water Management Institute.
- CEPA (Common Wealth Environmental Protection Agency) (1993). “Urban Storm Water” Australia.
- CRBC (2007): Cross River Broadcasting Cooperation, Calabar.
- CSIRO (2007). Climate change: Australia CSIRO and Bureau of meteorology. 137P ISBN 9781921232947. Canberra. Australia.
- David, B. (2004). Performance Indicator for urban storm drainages in developing countries. Elsevier vol. 4 issue 2 Pp 137-144.
- Dayaratne S. T., Perera, B. J. C. (2006). “Parameter optimization of urban storm water Drainages models. Proceedings of the 8th International Conference on urban storm Drainage, Sydney, Australia, 1768 – 1775.
- Dayaratne S.T. (2000). Modeling of urban storm water Drainage System, using Design and Analysis Programme (ILSA). Ph.D. Thesis Victoria University, Australia. Pp 21-23, 34.
- Gary, V.K. and Sing, J.B. (2010). Three state Markov Chain approach on the behaviour of rainfall. New York science journal, 3(12), 6
- Gobo, A.E. (1998). Relationship between Rainfall Trends and Flooding in the Niger-Benue River Basin. The *Journal of Meteorology*, 13 (132), Pp 34-37
- Hansingo, K. & Reasons, C.JC. 2009. Modeling the atmospheric response over southern Africa to SS1 forcing in the southeast tropical Atlantic and south west. International journal of climatogy, 1012 (April). PP 1001 – 1012.
- Hatt, B. E, Fletcher, T. D, Walsh, C. J and Taylor, S. L. (2004). The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. Environmental Management, 34(1), 112 – 124.
- Hortons, R.E (1930) Perceptual model of infiltration process. Hydrological process: 18 (17); 3447 – 3460.
- Hossain, S. J. (2015). Hydrological Modeling of Storm Water

- Drainage System due to frequent and intense precipitation of Dhaka City using storm water management Model (SWMM) American Geophysical Union, Full Meeting 2015 Abstract id H431-1667.
- Huary, G. H. and Xia, J. (2001). Barriers to sustainable water- quality management Journal of Environmental Management.61 (1), 1 – 23
- Ugbong, I.A (2000): An analysis of Runoff flow, channel characteristics and flood and erosion menace in the Calabar Drainage Basin. An Msc Research, Department of Geography and Regional Planning University of Calabar.
- UN – Water. 2007. Farms, Rivers and Markets: A whole – of – system. Approach to doing more with less water. Business case to the National Water Commission, Australia.
- Uyanah, M.E (2006). Functional correlates of the Reliability of Affective and Cognitive measures. Unpublished Msc. Dissertation in Research and statistics, Department of mathematics and statistics. University of Calabar: 45
- Valtanen, M., Sillanpaa, N. Setaia, H. (2014). Effects of hand use intensity of storm water runoff and its temporal occurrence in cold climates.
- Walski; T.M., Barnard, T.E., Durrans, S.R., Meadows M.E. (2002). Computer Application in Hydraulic Engineering: Connecting Theory to Practice. Haestad Press. Pp 22-23.
- Wang, D.Q. and Martiz J. S. (2007). Note on Testing a three – state markov chain for independence, journal of statistics, computation and simulation, (37), 61-68
- (2017) storm water management Model. Users manual.
- Willems, P, (2013.)Adjustment of extreme rainfall statistics accounting for multitude cadal climate associations journal of hydrology, 490, PP. 126-133.
- Wolski, P. (2009) Assessment of hydrological effects of climate change in the Okavango Basin Consultant Report for FAO, Draft. Cape Town.
- Wuebbles, D. Meehl, G. Hayhoe, K,(2014) CMIP5 Climate model Analyses, Climate Extreme in the United States American meteorological society, (April), Pp. 571 – 583.
- Yuk, S.L, Teo, F.Y, Roser, A.F (2013). Estimation of flood hazard Risk relating to vehicles.
- Zoppou, C. (2001). Review of Urban Storm water model in environmental modeling and software 16(3), Pp 195-231.