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Research Article

DETERMINATION OF URBAN STORM WATER DRAINAGE SYSTEMS MODELING FOR PART OF CROSS RIVER STATE NIGERIA

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Abstract

This Dissertation is on 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 was obtained. To check for multicollinearity, variance inflation factor (VIF) was used and VIF values of 1.853, 1.595, 1.300 and 0.011 were obtained respecting Area, Depth, Velocity and Width respectively. The model when applied will enhance the prediction of the adequate of the density of the drains to accommodate the storm runoff generated in the area. 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: Storm water, Drainage, Urbanization, Modeling, Discharge, Catchment area.

INTRODUCTION

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. The second type of water requiring drainage, storm water, is rain water (or water resulting from any form of precipitation) that has fallen on a built –up area. If storm water is not drained properly, it will cause inconveniences, flooding and further health risks. It contains some pollutants, originating from rain, the air or the catchment surface. 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 interface with the public and the environment. Urban drainage defines the systems which have been designed to drain wastewater and storm water out of populated areas. However, drainage is necessary to handle wastewater generated by populations and storm water generated by rain events. Thus, Urban drainage is at the interface between populations (public) and their environment as presented in Figure 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.

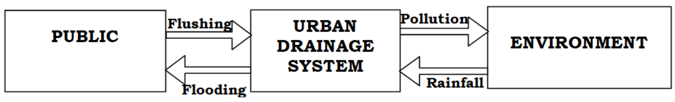

Fig. 1. Interfaces with the public and the environment

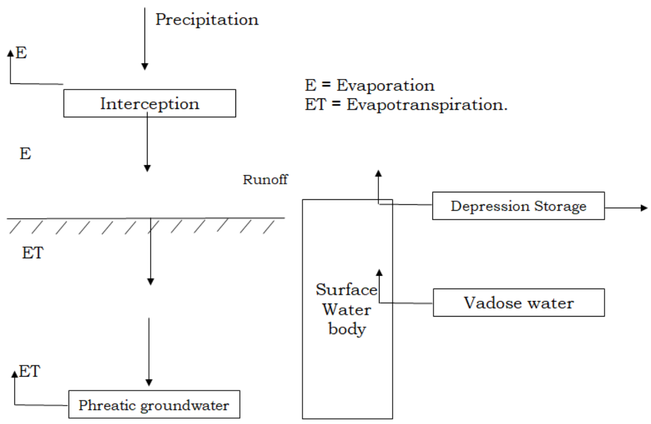

Fig. 2. Rainfall-runoff Components of hydrological Cycle

The rest of it overflows to the receiving waters. Flooding can be generated at different steps of the process. Natural channels which were in existence before urbanization is yet another factor, channel drains and storm drainage pipes are laid in the urbanized area to convey runoff rapidly to stream channels. Urban drainage systems should be designed to handle storm water and waste water with the aim of minimizing the problems caused to humans and the environment (Butler and Davis, 2004). Urbanization contributes to changes in the radiation flux and the amount of precipitation, evaporation and

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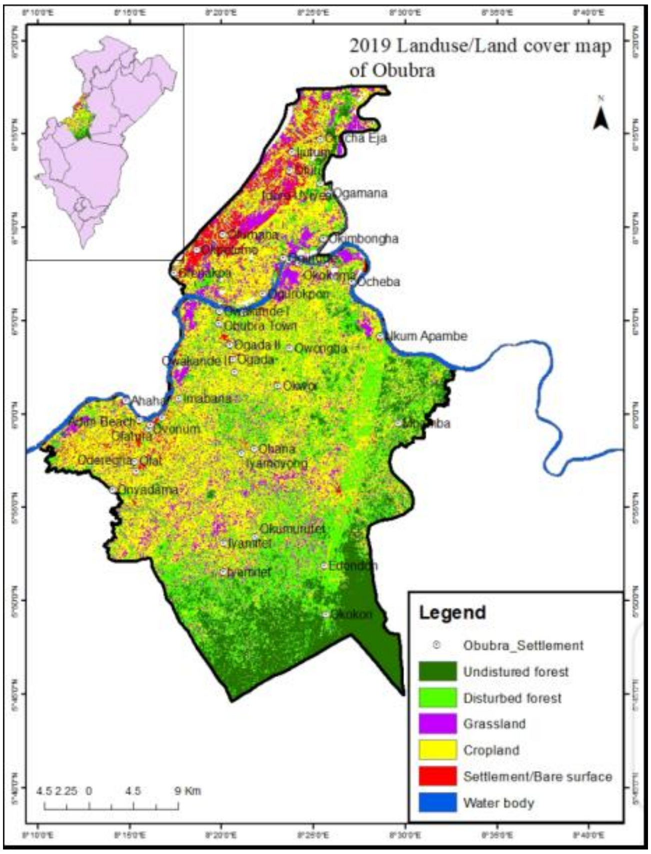
evapotranspiration, infiltration into soils, and consequently causes changes in the hydrological circle. The effects of large urban areas on local microclimate have long been recognized and occur as a result of changes in the energy regime, air pollution and air circulation patterns caused by building and or transformation of land cover.

MATERIALS AND METHODS

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 1115km^2 and lies between latitude 6^0 5^1N of the equator and longitude 8^0 18^1 E within the rainforest zone of south-south Nigeria. It has a population of 172,549 based on the 2006 census. 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.



Map 1. Map of study area

Equipment

The major equipment used for the river discharge measurement was a current meter, it is used in conjunction with a speedboat and was deployed to a laptop with a direct cable. The unit was set up, configured and operated using the laptop and win-river I software. A summary of installations is as follows;

- Deployment Equipment (Boats)
- Ocean-Science River Boat
- Bluetooth Radio Modems
- 12 Volt Lead Acid Re-Chargeable Batteries
- Ropes and Pulleys
- Laptops
- Hand Held GPS

An Acoustic Doppler Velocity Meter (ADVM), was now installed and configured. Configuration of the ADVM involves the selection of an appropriate measurement volume for the index velocity measurements, selection of the measurement interval and averaging interval and configuration of the ADVM to store internal quality – assurance (QA) data and velocity.

Plate 1. Configuration of the current meter

In a bit to achieve the general objectives of the study, the following specific tasks were undertaken among others;

i. Collection of data such as storm and discharge events, land-use conditions, soil and vegetation details for the catchment in order to observe the morphology of the drainage basin.
ii. Analyses of these collected data
iii. Selection of suitable storm events of the study catchments.

Data for the work may be classed into primary and secondary source data. Primary source data were obtained from the reconnaissance survey field experiments and analysis (rainfall, discharge, etc) whereas the secondary source data were obtained from review of existing literature, e-library, e-books and materials from the internet.

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.

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)

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).

Model Development

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

i. An aid to research
ii. As a tool for simulation and prediction
iii. 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.

Water Balance Process

The water balance process was used in the models between
’ Input from the catchment (rainfall);
’ Output from the catchment (runoff);
’ Losses from the catchment (evapo transpiration)

The model developed was done by the use of the following existing equations or models as a guide to suit the required objectives of the research.

The modified water balance equation 3 . 20 mentioned above may be summarized as;

$$R_r + R_c + R_i + R_t + S_i + L_g = E_i + T_p = S_e = O_g + D_s$$

Where,
R_r = recharge from rainfall
R_c = recharge from canal seepage;
R_i = recharge from field irrigation;
R_t = recharge from tanks;
S_i = Influent seepage from rivers;
L_g = Inflow from other business;
E_t = evapo transpiration ground water;
T_p = draft from ground water;
S_e = effluent seepage to rivers;
O_g = Outflow to other business and
D_s = change in ground water

The water balance is a method by which we can account for the hydrologic cycle of a specific area with emphasis on plants and soil moisture. In its simplest form, the equation reads inflow = outflow + recharge in storage Ø.

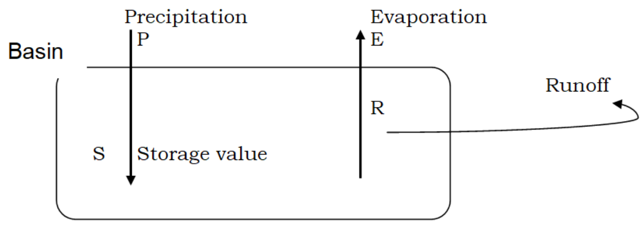


Fig. 2. Illustration of water balance diagram

RESULTS AND DISCUSSION

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)

Assumptions

$Q = 0, if\ A \leq or = 0$
$Q = 0, if\ V \leq or = 0$
$Q = 0, if\ D \leq or = 0$
$Q = 0, if\ W \leq or = 0$
$Q\ is\ not\ equal\ to\ 0, if\ and\ only\ if\ the\ values\ of\ A, V, D\ and\ W\ are \geq 0$

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

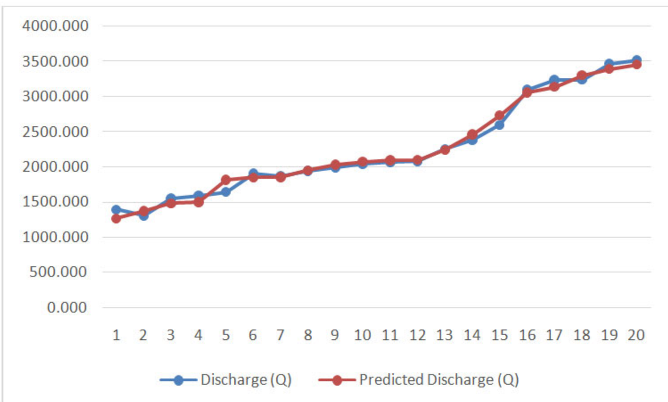


Fig 4.1. Measured and predicted plot of the model

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.

Table 1. Relationship between depth, width, velocity, area and discharges

	Depth(m)	Width	Velocity	Area	Measured Discharge (Q)	Predicted Discharge (Q)
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

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

$$r = \frac{20(111454944.3) - (45251.83)(45163.59)}{\sqrt{[20x111782808.20 - 2047728044)x(20x111248382.83 - 2039749699}}$$

$$r = \frac{2229098885 - 2043734978}{\sqrt{1879288120x185217957.4}}$$

$$r = \frac{185363907.1}{186568117.64}$$

$$r = 0.993545464491829$$

$$r = 0.994$$

Table 4.2. The Pearson correlation between measured and predicted discharges

X	Y	xy	x^2	y^2
3247.93	3306.30	10738628.2	10549024.08	10931640.19
3107.55	3060.10	9509391.925	9656838.07	9364197.08
2602.25	2732.36	7110271.716	6771703.24	7465767.78
2384.57	2463.78	5875069.049	5686187.40	6070224.90
2258.18	2241.27	5061173.135	5099362.76	5023269.52
2078.79	2099.12	4363628.775	4321356.02	4406315.06
2072.69	2093.81	4339812.852	4296047.98	4384023.57
2048.31	2072.54	4245197.356	4195559.11	4295422.88
1993.58	2029.05	4045067.043	3974352.64	4117039.64
1946.85	1950.73	3797784.273	3790229.59	3805354.01
1905.85	1848.73	3523401.724	3632275.14	3417791.67
1867.88	1851.84	3459011.943	3488971.13	3429310.02
3522.87	3457.06	12178782.45	12410638.40	11951258.04
1644.43	1812.04	2979788.583	2704165.50	3283504.65
3475.20	3397.76	11807868.33	12076994.19	11544739.72
1593.83	1494.59	2382127.002	2540299.17	2233803.45
1553.55	1476.71	2294138.157	2413512.33	2180668.32
3242.21	3141.39	10185070.79	10511954.22	9868352.24
1397.25	1264.17	1766358.296	1952298.31	1598127.51
1308.07	1370.25	1792372.677	1711038.94	1877572.59
45251.83	45163.59	111454944.3	111782808.20	111248382.83

Table 4.3. Relationship between measured and predicted discharges for calibration of the model

X	Y	xy	x^2	y^2
3247.93	3306.30	10738628.2	10549024.08	10931640.19
3107.55	3060.10	9509391.925	9656838.07	9364197.08
2602.25	2732.36	7110271.716	6771703.24	7465767.78
2384.57	2463.78	5875069.049	5686187.40	6070224.90
2258.18	2241.27	5061173.135	5099362.76	5023269.52
2078.79	2099.12	4363628.775	4321356.02	4406315.06
2072.69	2093.81	4339812.852	4296047.98	4384023.57
2048.31	2072.54	4245197.356	4195559.11	4295422.88
1993.58	2029.05	4045067.043	3974352.64	4117039.64
1946.85	1950.73	3797784.273	3790229.59	3805354.01
23740.68	24049.05	59086024.32	58340660.89	59863254.62

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

$$r = \frac{10(59086024.32) - (23740.68)(24049.05)}{\sqrt{[10x58340660.89 - 563620094)x(10x59863254.62 - 578356971.36)}}$$

$$r = \frac{590860243.2 - 570940800.4}{\sqrt{40118296377723}}$$

$$r = \frac{19919442.8}{20029552.26}$$

$$r = 0.994502649955891$$

$$r = 0.995$$

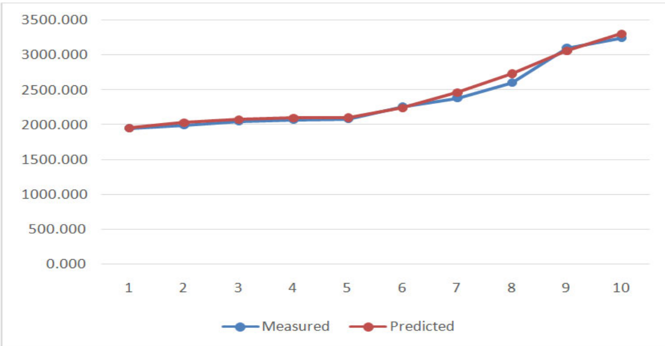


Fig 4.2. Plot showing model calibration

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	12178782.45	12410638.40	11951258.04
1644.43	1812.04433	2979788.583	2704165.50	3283504.65
3475.2	3397.7551	11807868.33	12076994.19	11544739.72
1593.83	1494.5914	2382127.002	2540299.17	2233803.45
1553.55	1476.70861	2294138.157	2413512.33	2180668.32
3242.21	3141.39336	10185070.79	10511954.22	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	52368919.95	53442147.32	51385128.21

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

$$r = \frac{10(52368919.65) - (21511.14)(21114.53)}{\sqrt{[10x53442147.32 - 462729350.95)x(10x51385128.21 - 445823578.13)}}$$

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

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

$$r = 0.995069916234791$$

$$r = 0.995$$

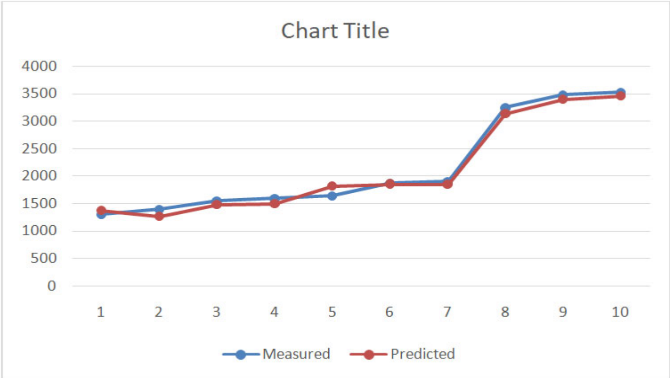


Fig 4.3. Plot showing model calibration

The table 4.5 presents the relationship in the matrix between variables, how each variable relates with each other. The result from the correlation matrix for the variables shows that, there is a significant positive relationship between discharged and Cross-sectional area, there is significant positive relationship between discharge and depth and there is significant positive relationship between discharge and width and a strong positive relationship between discharge and velocity. The result shows that as depth, width and cross-sectional area increase, discharged also increases significantly. Discharged was found to show significant positive relationship with depth, width and cross sectional but not with velocity.

Model Formulation

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. The choice of drainage coefficient can be influence by climate, soils and crops grown and it is based on local conditions, experience and judgment.

Table 4.7. Multicollinearity test tablefor Area, Depth, Width and Velocity

Variables	VIF
Area	1.835
Depth	1.595
Width	0.011
Velocity	1.300

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. Rainfall frequency analyze are used extensively in the design of systems to handle storm runoff, including roads, culverts and drainage systems. Drainage coefficient is the design capacity of the drainage system expressed as a depth of water removed in 24 hours. It should be chosen to economically remove excess water from the top part of the root zone within 24 to 48 hours.

Table 4.6. Descriptive statistics for the variables (Area, and discharge) used in the model development

SUMMARY OUTPUT									
Regression Statistics									
Multiple R	0.993546								
R Square	0.987134								
Adjusted R Square	0.983703								
Standard Error	89.77444								
Observations	20								
ANOVA									
	df	*SS*	*MS*	*F*	*Significance F*				
Regression	4	9275514	2318879	287.7216833	5.56189E-14				
Residual	15	120891.8	8059.45						
Total	19	9396406							
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*	
Intercept	-2417.747	419.890	-5.758	0.000	-3312.722	-1522.772	-3312.722	-1522.772	
Depth(m)	11.677	89.358	0.131	0.898	-178.786	202.140	-178.786	202.140	
Width	0.329	0.822	0.400	0.695	-1.423	2.081	-1.423	2.081	
Velocity	1772.149	65.784	26.939	0.000	1631.933	1912.366	1631.933	1912.366	
Area	1.243	0.204	6.080	0.000	0.807	1.679	0.807	1.679	

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 result coefficient (c) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a large value for areas with low infiltration and high runoff (pavement, steep gradient) and lower for permeable, well vegetated areas (forest, flat land). 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 ruleof-thumb is also recommended in the design of the storm drainage systems in the area. 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.

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