



Drainage Network Analysis and Incidence of Flooding In Bonny Island, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author ILN designed the study, performed the computer simulations, wrote the protocol and the first draft of the manuscript and managed literature searches. Authors OLU and CCD managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The incidence of occasional flooding of an estate, a tank farm in Bonny Island, Niger Delta was investigated. The study was carried out to identify the remote causes of flooding and in turn proffer a solution. Detail field investigation involved identification of thirty one road side drains of rectangular cross-section; measurement of drains inverts (spot heights) at selected locations yielded estimates of longitudinal slopes (0.000416 – 0.0074 m/m), a case of very mild slopes. The invert profiles of 15 road side drains indicated a case of inconsistent slopes, a mix of positive and negative slopes over short intervals, the observation accounts for siltation and ponding in the drains. The redesigns of the existing drains were actualized via the use of MODRAIN code, based on the principle of best hydraulic section with input data options for rectangular or trapezoidal channels; constant or variable bottom slopes and runoff coefficient(s). A comparison of the existing and newly designed drains with respect to cross-sectional areas confirmed that 80% of the existing drains are oversized, in what is captioned "Bigger existing drains". Apparently, the issue of occasional flooding of the Estate cannot be all blamed on inadequate drain size but on existing bottom slopes (very mild slopes) of the drains.

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1. INTRODUCTION

Many urban areas in southern Nigeria, Bonny Island inclusive experience different levels of flooding incidence arising from different degrees of drainage failures. Flooding in any developed system, estate, urban or semi-urban area deals with excess water in the drainage system. And it arises as a result of any or a combination of the following factors [1,2]: (i) When the natural routes of overland flow/runoff in a watershed are completely blocked with earth fills or encroached upon with physical infrastructures (that is, built-up areas); (ii) Loss of natural infiltration/percolation galleries due to excessive pavement attributable to large scale urbanization without proper drainage systems design; (iii) Seasonal flashfloods and uncontrolled release of water from water bodies like dams etc. (e.g., in 2012, flooding was recorded in Nigeria due to uncontrolled release of water from Lagdo Dam in the northern province of Cameroun); (iv) If the design capacity of man-made channel (gutter/culvert) is exceeded with higher rainfall intensities, return periods or when such drain is silted or blocked with debris/sediments; and (v) Due to poor drainage construction wherein flat slope is imposed on a gutter with a complete loss of gravity flow, or when a large sized gutter empties into a small one or similar size at periods of full gutter flow. This applies to a system of network of drains of different sizes.

The last two factors are concerned with inadequate size of gutters/culverts and poor construction work (e.g., lack of gravity flow due to flat slopes and, small gutter sizes where large capacities are needed). However, the first factor deals with encroachments on natural drain routes.

Encroachments as used herein are any occupancy of the natural drain routes or river flood plains for highway use, buildings and other physical infrastructures. In case of man-made drains or natural drain routes in urban areas, encroachment of minute extent always produce impacts on flooding.

2. MATERIALS AND METHODS

2.1 Study Area

Bonny Island (4°25' 59" N and 7°9' 0" E), located in the Nigerian Atlantic coastline otherwise

known as Gulf of Guinea along the southern part of Nigeria is the study area [3]. Bonny Island is part of the Niger Delta which constitutes 7.5% of Nigeria's landmass and 27% of its population. The Niger Delta is the centre of oil and gas activities in Nigeria since 1956 when the first oil well was drilled in Olobiri, Bayelsa State. Bonny Island is the home of two industrial estates, the Nigeria Liquefied Natural Gas (NLNG) and Shell Petroleum Development Company (SPDC) oil Terminal. The premises housing the SPDC oil terminal (including a Tank Farm) is the study area with thirty one (31) network of roads and side drains (see Fig. 1).

2.2 Most Efficient Hydraulic Cross-Section for Drains

In drainage design and construction, it is well known that the cost of drainage increases as the size of the gutter design capacity is increased. The application of the concept of "**Best (or most efficient) Hydraulic section**" on gutter or culvert, is necessary for cost reduction during actual construction. In order to reduce construction cost the designer aims at minimizing the cross-sectional area [4]. It has been established that the most effective cross-section is one in which its wetted perimeter is minimum [5,6]. By the definition of Hydraulic radius, R_h (see Equation 3) the minimization of wetted perimeter may be possible with the maximization of R_h . Hence, a channel maximum R_h , not only results in optimum hydraulic design but also tends towards a section of minimum cost (Fig. 2) and it may be derived as follows [1,6].

Hydraulic radius, R_h for a trapezoidal channel:

$$R_h = \frac{A}{P} = \frac{by + zy^2}{b + 2y(1 + z^2)^{1/2}} \quad (1)$$

$$R_h = \frac{A}{\frac{A}{y} - zy + 2y(1 + z^2)^{1/2}} \quad (2)$$

Where: R_h = Hydraulic radius (m); A = Cross-sectional area (m^2); P =Wetted perimeter (m); z = Side slope (see Fig. 2, if z = 0, a rectangular channel results); b = Bottom width (m); and y = Depth of flow (m).



Fig. 1. Map of study area, Bonny Estate with road networks and side drains
Source: Google [3]

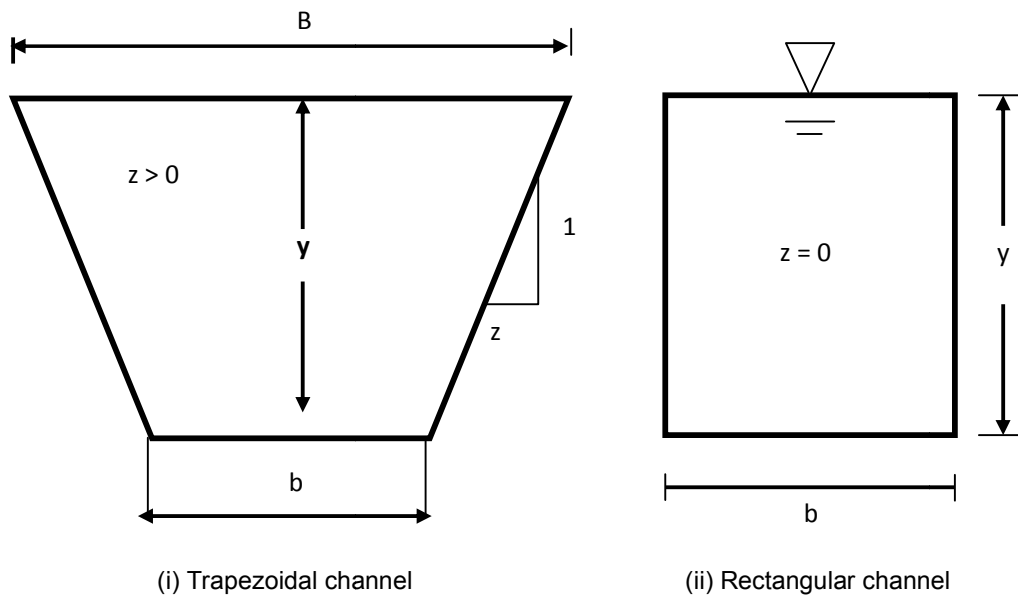


Fig. 2. Typical trapezoidal and rectangular cross-sections

Where: y = Depth of flow (m); b = Channel bottom width (m); B = Channel top width (m); and z = Side slope (dimensionless), if $z = 0$, the cross-section becomes rectangular

Differentiating R_h with respect to y and equating to zero gives $A = y^2 (2\sqrt{1+z^2} - z)$, which when substituted into Equation (1) yields the maximum hydraulic radius:

$$R_{h \max} = \frac{y}{2} \quad (3)$$

The sizing of each drain is made via Chezy-Manning's formula:

$$Q_d = 1/n AR_h^{2/3} S_0^{1/2} \quad (4)$$

Where: n = Manning's roughness coefficient; S_0 = Normal channel slope; and Q_d = Design discharge or peak runoff (m^3/s)

Combining Equations (3) and (4), we obtain values for y and b as:

$$y = \left[\frac{1.5878nQ_d}{(2\sqrt{1+z^2} - z) S_0^{1/2}} \right]^{3/8} \quad (5)$$

and

$$b = 2y \left[2\sqrt{1+z^2} - z \right] \quad (6)$$

Evaluation of Equations (5) and (6) for the various gutters are as presented later.

2.3 Drains' Network System

The field survey of the existing road side drains yields a configuration of network of drains as depicted in Fig. 3. Three major drain classifications are made, namely: (a) The main drains; (b) Intermediate drains, and (c) Tributary drains. The flow pattern (see Fig. 3) is such that the flows originating from tributary drains are emptied into the intermediate drains. The intermediate drain empties into the main drain. Eventually, the flow from the main drain is discharged into Last Line of Defence (LLOD) system which ultimately is discharged into Bonny River (taken as water body in Fig. 3). The LLOD is a runoff receiving unit where oil is separated, if any before discharge into Bonny River.

On most roads, drains exist for the right and left sides. Herein, flows on the right and left side drains of a particular road are represented as

flows on "East" and "West" side drains. For instance, consider Road 4, the two side drains are usually designated as Roads 4E and 4W, respectively. This illustration is useful to help interpret the road side drain notations employed for computer simulations.

2.4 Drain Inverts, Profiles and Occasional Flooding

Given the availability of drain inverts for various road side drains, it became necessary to plot the chainage against invert levels, resulting to invert profiles of drains. Invert profiles for a total of fifteen road side drains were generated with Figs. 4-9 as typical illustrations. For Road 2 (see Fig. 4) both side drains flow in the same direction. However, a lot of fluctuations (rise and fall) on invert levels are very visible, and it slows down flow, occasionally induces siltation, particularly with a very mild longitudinal bottom slope. The profiles of drains along roads 1, 2, 3, 4, 10 and 12 (left) are inconsistent (see Figs. 4 - 9). Field observation confirmed the existence of stagnant water along roads 10 and 12 (right) which is not unconnected with the inconsistent drain profiles, that is, the rise and fall in drain invert levels.

Based on field observations on gutter flows in November and December (beginning of dry season), the analysis of gutter inverts versus profiles, and comparison of cross-sectional areas of existing drains and the newly designed equivalents. The following factors are found responsible for the incidence of occasional flooding in the study area: (1) The average longitudinal bottom slopes for existing road side drains (0.00075 m/m) is very mild, and gutter flow is very sluggish and thus, promotes siltation and flooding; (2) Existing drain profiles (plot of invert levels against distance) in some drains are inconsistent, a mix of positive and negative slopes at short distances along the length of the drain (see Figs. 4-9). This anomaly is responsible for stagnant water observed in drains along roads 12 and 13B (right drain); (3) Eighty percent (80%) of the existing drains are rated as bigger drains with respect to the newly designed drains equivalents (mostly the tributary drains and few intermediate drains). In effect, incidence of flooding should not be all blamed on existing drain sizes, rather the other two factors stated earlier should carry greater weight.

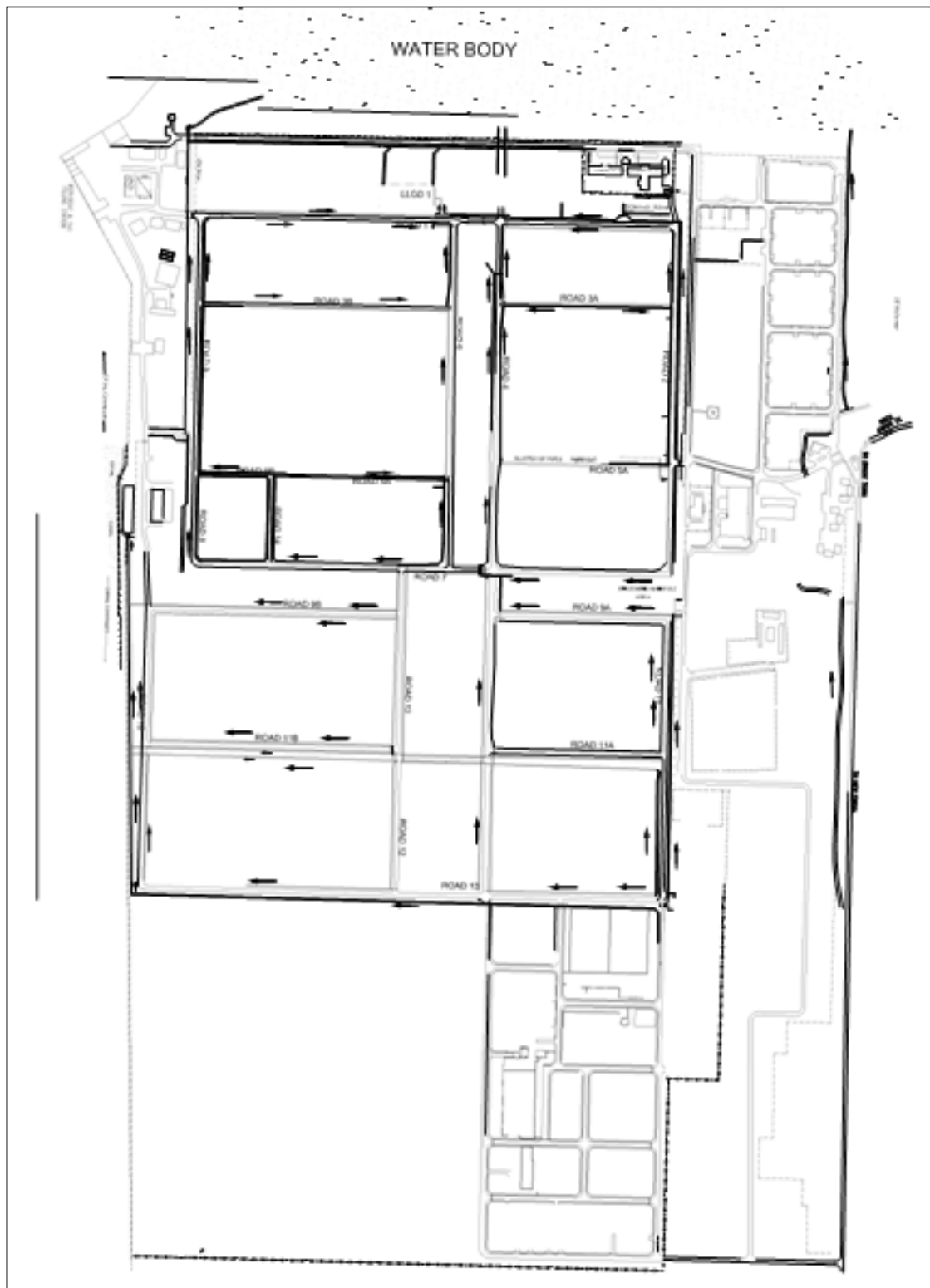


Fig. 3. Existing road network of drains and flow directions

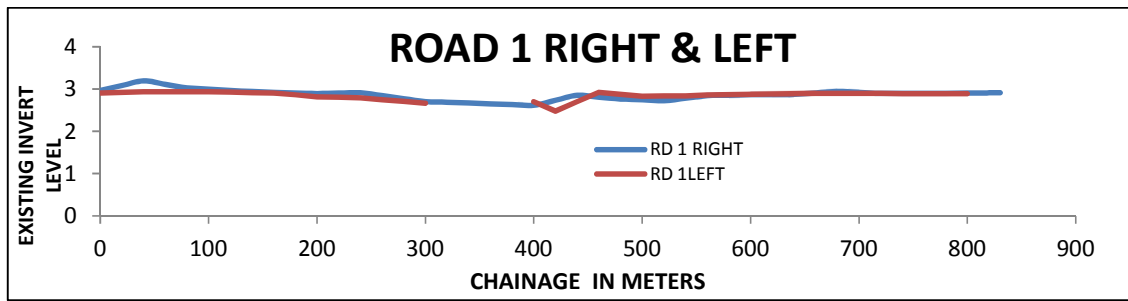


Fig. 4. Drain profiles for road 1, E & W

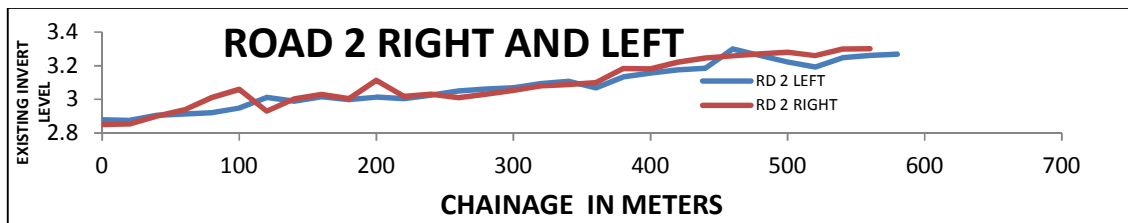


Fig. 5. Drain profiles for road 2, E & W

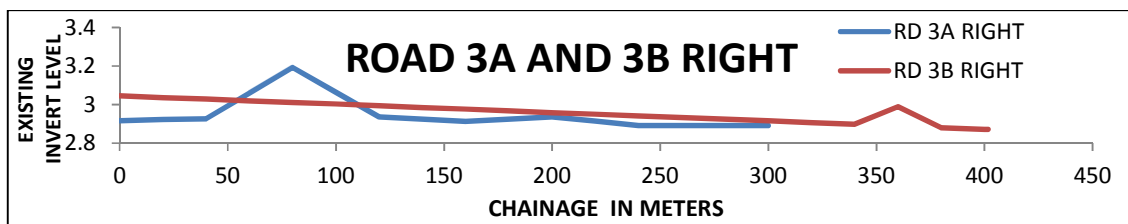


Fig. 6. Drain profiles for roads 3A & B

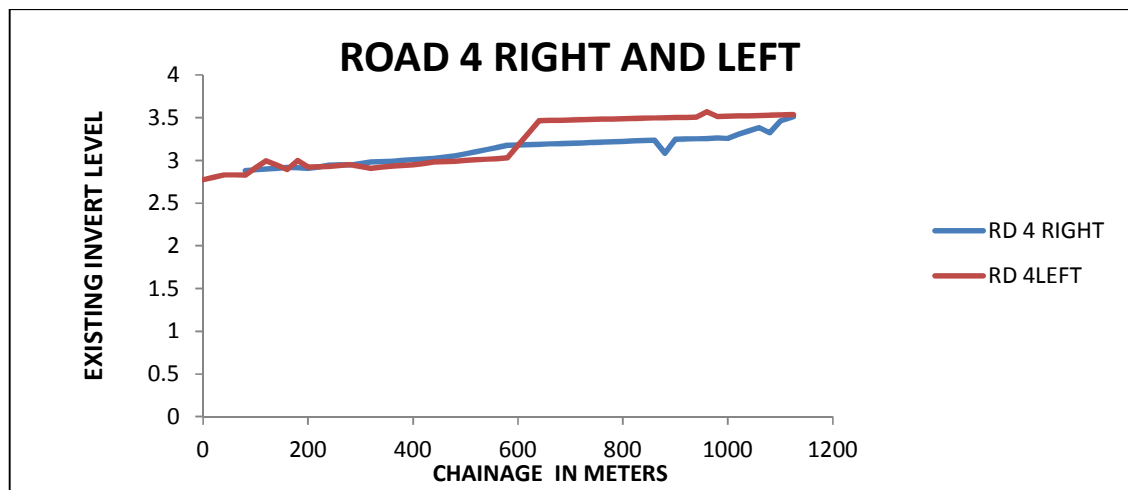


Fig. 7. Drain profiles for road 4, E & W

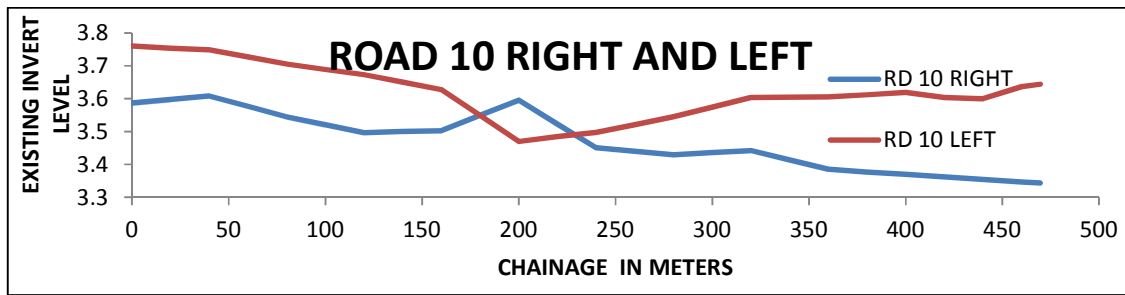


Fig. 8. Drain profiles for road 10, E & W

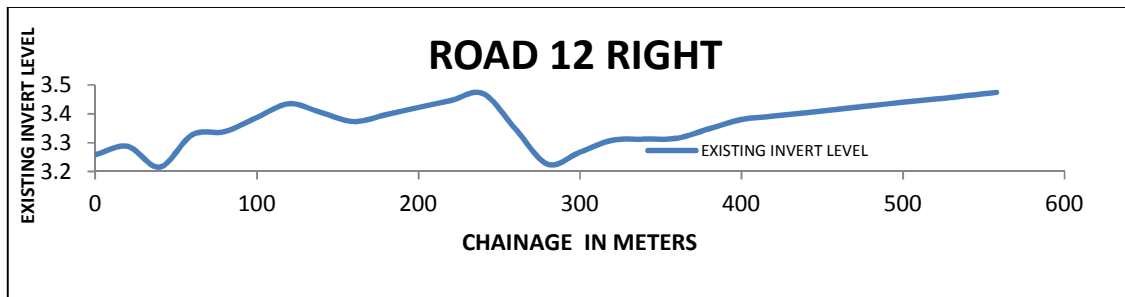


Fig. 9. Drain profile for road 12, E

2.5 Redesign of Existing Network of Drains in Bonny Estate

The newly designed drains have to conform to the layout of the existing network of drains in the study area (see Fig. 3). In other words, all the existing road side drains, are redesigned based on the field survey data generated, applicable rainfall data and basic principles of hydraulics (the best hydraulic section). The actual redesign of the existing drains covers a total of 31 road side drains in a network flow system.

The design approach for the **most efficient or best hydraulic section** was achieved by the adoption of computer code, MODRAIN [6]. Selected gutter cross-section has two options (rectangular or trapezoidal). The code is written in both Visual Basic and FORTRAN 77 language and is of two parts, the MAIN program and a subroutine, SDRAIN. In the MAIN program, all the input data are read and echo-checked (or reprinted). Further to this, are the activities of both the main program and SDRAIN which are highlighted in the course of design computations. Field measurements of drain inverts or spot heights in selected locations are employed for initial estimates of gutter longitudinal, slope, S_0 . The range of S_0 values for road side drains are 0.000416 to 0.0074 m/m, that is, very mild slopes.

Estimates of overland flow (catchment runoff) for all drains are made in the main program. The sequence begins with the estimate of time of concentration, t_c using Equation (7) [7], then the rainfall intensity [8] via the evaluation of Equation (8), and thereafter, the computation of runoff into the drain, using the rational formula, Equation (9). The recommendation of Nigeria Highway design manual, part 1 of the Federal Ministry of Works and Housing [9] for urban runoff computation is the Rational formula or the Lloyd-Davis method. The choice of the Rational formula for runoff computation (Equation 9) is valid given that the entire catchment area is less than 10 km^2 .

The subroutine sizes the drain by way of computing depth and width values of each channel cross-section. Drainage calculations as adopted in this study were based on average rainfall intensity that has a return period of 10 years as recommended in the highway design manual, part-1 [9], without consideration to tidal events.

The Rainfall Intensity model (Equation 8) was developed with 11 year record from Bonny Island [8]. More recent studies on rainfall models in Nigeria are those of Port Harcourt city by Nwaogazie & Duru [10]; Uyo city by Etteh Aro & Partners [11]; Eket Urban by Gazems Ventures

[2]; Enugu city by Nwaogazie & Nwadike [12]; and selected cities in Southern Nigeria by Nwaogazie and Ologhadien [13]. The practical uses of rainfall frequency models are many.

In design of drainage system, flood control works and other hydraulic structures, the need always arises in selecting an appropriate design discharge corresponding to specific rainfall frequency, that is, the maximum discharge capacity a drain or structure is designed to carry is a matter of economics [10]. For instance, in culvert design, the size corresponding to a rainfall frequency of one in a hundred years would be far greater and more expensive to build than that of one in ten years. Thus, the need to develop accurate rainfall frequency models cannot be over emphasized.

Hydrologic empirical models for drain design

$$t_c = 0.01947L^{0.77} S^{-1/2} \quad (7)$$

$$i = 27,738.0/(t + 276.0) \quad (8)$$

$$Q = CiA / (3600 \times 1000) \quad (9)$$

Where: t_c = time of concentration (minutes); i = rainfall intensity (m/sec); C = runoff coefficient; L = length of the watershed (m), S = longitudinal slope (m/m), and A = Area (m^2)

Note: For Equation (9), the denominator '3600' is a conversion factor from hour to seconds while '1000' is to convert hectare to square metre; thus, Q becomes m^3/s .

The choice of rectangular or trapezoidal section is made beforehand *via* input data, before the subroutine is called. Addition of free board of 0.05 m to depth and width values is made. Thereafter, velocity for the designed gutter is computed and a check on velocity limits is made. If velocity value is less than 1.0 m/s, an upgrade of the estimated longitudinal slope, S_0 is made by a given percent. This is to avoid siltation in the drain. This slope upgrade is repeated many times as necessary and velocity, V is correspondingly recomputed and checked until $V \geq 1.0$ m/s.

Similarly, if velocity, V is higher than 3.0 m/s, then a reduction of slope, S_0 is made to avoid erosion. In each cycle of slope reduction by a given percent, velocity is recomputed and

compared with set limits. And it is terminated once $V \leq 3.0$ m/s. Once all the drains have been sized by the Subroutine, SDRAIN, then the simulated results per drain are printed out and program is terminated.

2.6 Input Data Preparation

One simplification found in MODRAIN code is the allowance for estimates of longitudinal bottom slopes of all drains to be made and entered as input data. A total of 8 sets of input data are required to run MODRAIN code, namely: (i) Title the user wishes to have printed; (ii) Drain descriptive parameters (4 parameters) namely: number of drains in the network; side slope, Z (see Fig. 2); return period for rainfall event in years; and Manning's coefficient; (iii) Length of each drain route in metres; (iv) Estimated longitudinal bottom slope of drain (m/m); (v) Catchment area associated with each drain (m^2); (vi) 'YES' or 'NO' option if runoff coefficient is constant for all drains; (vii) Constant value of runoff coefficient or variable values; and (viii) Regressed coefficients of Equation (8), that is, the values of $A = 27,738$ and $B = 276$.

3. DISCUSSION OF SIMULATED RESULTS

A total of thirty-one drains were identified as road side drains for redesign. Appropriate input data were entered in consonance with input data variables. For the simulated design drains, the application of the best hydraulic sections is inherent. The efficiency of the design is manifested in the sizing of the drains. The depth to width ratio is 1:2, and this is very obvious for the rectangular drains. The input data set and corresponding simulated output for the 31 drains are as presented in the Appendix. A comparison of the existing and newly designed drains with respect to cross-sectional areas are necessary to validate the simulated results. The percentage difference in cross-sectional area stands as the sole parameter for the comparison. Two observations are noted with respect to Smaller Existing Drains (SED), and that of Bigger Existing Drains (BED) (see Table 1). On the average, a total of 20 out of 25 drains (80%) are recorded as "bigger existing drains".

The smaller existing drains are mainly for roads 1 and 4 that may be taken as the main (receiving) drains. As such their tributary catchment areas should be the summation of all those drains emptying into them. This is where the application

Table 1. Percent difference in cross-sectional areas of existing and newly designed drains

S/No	Road name	Existing drain			Newly designed drain			% diff. in area	Remarks
		Depth, (m)	Width, (m)	x-sectn area, (m ²)	Depth, (m)	Width, (m)	x-sectn area, (m ²)		
1	1A	0.69	1.20	0.828	1.172	2.294	2.689	-224.7	SED ⁺
2	1B	0.69	1.20	0.828	1.289	2.524	3.288	-292.3	SED
3	2E	0.67	1.18	0.791	0.492	0.934	0.4597	+41.9	BED [±]
4	3AE	0.68	0.98	0.6664	0.40	0.750	0.300	+55.0	BED [±]
5	3AW	0.68	1.00	0.680	0.677	1.30	0.8801	-29.4	SED
6	4E	0.46	0.99	0.4554	0.765	1.48	1.133	-148.6	SED
7	4W	0.68	0.98	0.6664	0.715	1.38	0.9867	-48.1	SED
8	5AE	0.58	1.17	0.6786	0.413	0.777	0.321	+52.8	BED
9	6E	0.68	1.17	0.7956	0.566	1.081	0.6119	+23.1	BED
10	7E	0.69	1.20	0.828	0.493	0.936	0.4614	+44.3	BED
11	8E	0.48	4.10	1.968	0.631	1.212	0.7648	+61.1	BED
12	8W	0.67	1.20	0.804	0.727	1.404	1.0207	-27.0	SED
13	9AE	0.40	1.0	0.40	0.4552	0.8603	0.392	+2.0	BED
14	9AW	0.32	1.50	0.48	0.4638	0.8776	0.407	+15.2	BED
15	9BE	0.50	1.0	0.50	0.387	0.724	0.2802	+44.0	BED
16	9BW	0.50	1.0	0.50	0.4295	0.809	0.3475	+30.5	BED
17	10E	0.68	1.20	0.816	0.387	0.724	0.2802	+67.6	BED
18	11A & BE	0.72	1.20	0.864	0.462	0.873	0.4033	+53.3	BED
19	11A & BW	0.72	1.20	0.864	0.5215	1.013	0.5384	+37.7	BED
20	13E	1.70	1.50	2.55	0.559	1.168	0.597	+76.6	BED
21	14E	0.68	1.20	0.816	0.3411	0.6322	0.2156	+73.6	BED
22	14W	0.68	1.20	0.816	0.373	0.696	0.259	+68.2	BED
23	16W	1.70	2.23	3.791	0.6094	1.169	0.651	+82.8	BED

Note: + SED = Small existing drain; ± BED = Bigger existing drain; x-sectn = cross-section, (m²)

of the concept of drains' network modeling is truly exercised. The runoff to a particular drain in the network (tributary, intermediate or main drain) is obtained with respect to the contributory area, as exemplified in Equation (9).

A number of drainage network design principles are available in literature in form of manuals and/or case studies [14-17]. The emphases are more on various approximate methods for modeling storm water flow in drains, for instance, using Muskingum-Cunge channel flow routing [14]; and use of rational formula and Manning's equation [15-17]. Network modeling as exemplified in Bonny Estate study is in agreement with the design principles of [15-17] but the networking is its unique feature.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Based on the results of this study, the following conclusions are drawn: A total of thirty one

existing road side drains in the study area have been classified as: (a) Tributary drains; (b) Intermediate drains; and (c) Main drains. The flow pattern is such that flow originating from tributary drains is emptied into intermediate drains which equally empty into main drains. Only two main drains are in the study area. Each main drain discharges into Last Line of Defence (LLOD) system and ultimately into Bonny river. Existing drain profiles (invert levels versus distance) in some drains are inconsistent, that is, a mix of positive and negative slopes at short intervals along the length of the drain. This anomaly on road side drains is found along eleven drains and is responsible for stagnant water observed in drains along roads 12 and 13B (right drain).

Eighty percent (80%) of the existing drains are rated as bigger drains with respect to the newly designed equivalents (mostly the tributary and few intermediate drains). In effect, the incidence of flooding should not be all blamed on existing drain sizes rather on existing slopes (very mild of average value of 0.00075 m/m).

4.2 Recommendation

Based on the findings of the study, the inadequacies of the existing drains in the study area, all the road side drains identified in the study having a mix of positive and negative bottom slopes should be reconstructed. These should cover the road side drains found along roads 2E & W, 4E & W, 5A-E, 10E & W, 11E & W, 12E and 13B, respectively. The invert profiles (bottom slopes) herein taken as adjusted slope (see Table A3 Appendix) for these drains should be strictly adhered to.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX-A

Table A1. Input data for road side drains in bonny estate

DESIGN OF DRAINAGE NETWORK FOR BONNY ESTATE: ROAD SIDE DRAINS

31	0.0	10.0	0.02				
830.2	795.4	556.5	580.0	281.7	401.64	Length of drain route	
1122.0	1122.0	120.0	430.0	565.3	785.3		
880.0	578.0	285.0	280.0	409.0	409.0		
469.6	469.6	869.0	869.0	869.0	869.0		
557.8	243.6	877.9	136.8	136.8	440.0		
707.9							
0.001308	0.000784	0.000508	0.000671	0.00173	0.000416	Bottom slopes	
0.000461	0.000862	0.00202	0.00091	0.00118	0.0074		
0.00292	0.00113	0.000463	0.00211	0.00061	0.000861		
0.00147	0.000663	0.00512	0.00126	0.00512	0.00126		
0.00189	0.00185	0.00134	0.00140	0.000762	0.00147		
0.00147							
186501.	199402.	10149.0	10266.0	8076.0	22366.0	Catchment areas	
42856.0	42856.0	9050.0	9820.0	21039.9	31480.0		
44445.2	42935.2	6845.0	6820.0	9810.0	9810.0		
7197.0	7197.0	19456.6	19456.6	12807.0	12807.0		
17541.0	9718.0	23095.0	4255.4	4255.4	27563.0		
28903.0							
YES							
0.8							
27738.0	276.0						

Table A2. Output on simulated thirty-one drains

DESIGN OF DRAINAGE NETWORK FOR BONNY ESTATE: ROAD SIDE DRAINS						
=====						
INPUT DATA						
=====						
TOTAL DRAIN DESIGNATIONS = 31						
RETURN PERIOD = 10.0 YEARS						
MANNINGS COEFFICIENT = 0.2000E-01						
DRAIN SIDE SLOPE = 0.00						
RAINFALL-RUNOFF ESTIMATES [±]						
=====						
LOCATN	LENGTH	SLOPE	CMT.AREA	T.CONC	R.INTSTY	RUNOFF
=====	=====	=====	=====	=====	=====	=====
1	.8302E+03	.1308E-02	.1865E+06	.9524E+02	.2075E-04	.3097E+01
2	.7954E+03	.7840E-03	.1994E+06	.1190E+03	.1950E-04	.3111E+01
3	.5565E+03	.5080E-03	.1015E+05	.1123E+03	.1984E-04	.1611E+00
4	.5800E+03	.6710E-03	.1027E+05	.1009E+03	.2044E-04	.1679E+00
5	.2817E+03	.1730E-02	.8076E+04	.3603E+02	.2469E-04	.1595E+00
6	.4016E+03	.4160E-03	.2237E+05	.9655E+02	.2068E-04	.3701E+00
7	.1122E+04	.4610E-03	.4286E+05	.2023E+03	.1611E-04	.5523E+00
8	.1122E+04	.8620E-03	.4286E+05	.1479E+03	.1817E-04	.6231E+00
9	.1200E+03	.2020E-02	.9050E+04	.1728E+02	.2627E-04	.1902E+00
10	.4300E+03	.9100E-03	.9820E+04	.6880E+02	.2235E-04	.1756E+00
11	.5653E+03	.1180E-02	.2104E+05	.7459E+02	.2198E-04	.3699E+00
12	.7853E+03	.7400E-02	.3148E+05	.3836E+02	.2451E-04	.6173E+00
13	.8800E+03	.2920E-02	.4445E+05	.6667E+02	.2249E-04	.7995E+00
14	.5780E+03	.1130E-02	.4294E+05	.7754E+02	.2179E-04	.7486E+00
15	.2850E+03	.4630E-03	.6845E+04	.7028E+02	.2225E-04	.1218E+00
16	.2800E+03	.2110E-02	.6820E+04	.3247E+02	.2498E-04	.1363E+00
17	.4090E+03	.6100E-03	.9810E+04	.8086E+02	.2159E-04	.1694E+00
18	.4090E+03	.8610E-03	.9810E+04	.6806E+02	.2239E-04	.1758E+00
19	.4696E+03	.1470E-02	.7197E+04	.5793E+02	.2307E-04	.1328E+00
20	.4696E+03	.6630E-03	.7197E+04	.8627E+02	.2127E-04	.1225E+00
21	.8690E+03	.5120E-02	.1946E+05	.4986E+02	.2364E-04	.3680E+00
22	.8690E+03	.1260E-02	.1946E+05	.1005E+03	.2046E-04	.3185E+00
23	.8690E+03	.5120E-02	.1281E+05	.4986E+02	.2364E-04	.2423E+00
24	.8690E+03	.1260E-02	.1281E+05	.1005E+03	.2046E-04	.2097E+00
25	.5578E+03	.1890E-02	.1754E+05	.5833E+02	.2305E-04	.3234E+00
26	.2436E+03	.1850E-02	.9718E+04	.3115E+02	.2509E-04	.1950E+00
27	.8779E+03	.1340E-02	.2310E+05	.9823E+02	.2059E-04	.3804E+00
28	.1368E+03	.1400E-02	.4255E+04	.2297E+02	.2577E-04	.8774E-01
29	.1368E+03	.7620E-03	.4255E+04	.3113E+02	.2509E-04	.8540E-01
30	.4400E+03	.1470E-02	.2756E+05	.5510E+02	.2327E-04	.5131E+00
31	.7079E+03	.1470E-02	.2890E+05	.7947E+02	.2168E-04	.5012E+00

[±] Notation: CMT. AREA = Catchment Area; T.CONC. = Time of Concentration;
R.INTSTY = Rainfall Intensity.

Table A3. Sizing of drains, velocities, discharges and adjusted slopes

S I Z E D D R A I N S ±					
LOCATN	DEPTH	WIDTH	VELOCITY	DRAIN CAPTY	ADJ.SLOPE
Rd 1A	0.1172E+01	0.2294E+01	0.1152E+01	0.3097E+01	0.1308E-02
Rd 1B	0.1287E+01	0.2524E+01	0.1159E+01	0.3766E+01	0.9800E-03
Rd 2E	0.4922E+00	0.9343E+00	0.1062E+01	0.4881E+00	0.3028E-02
Rd2W	0.4762E+00	0.9025E+00	0.1067E+01	0.4585E+00	0.3200E-02
Rd 3A E	0.4001E+00	0.7502E+00	0.1087E+01	0.3264E+00	0.4224E-02
Rd 3B E	0.6770E+00	0.1304E+01	0.1068E+01	0.9429E+00	0.1984E-02
Rd 4E	0.7647E+00	0.1479E+01	0.1092E+01	0.1236E+01	0.1759E-02
Rd 4W	0.7150E+00	0.1380E+01	0.1021E+01	0.1007E+01	0.1684E-02
Rd 5A E	0.4133E+00	0.7765E+00	0.1075E+01	0.3449E+00	0.3945E-02
Rd 5A W	0.4593E+00	0.8687E+00	0.1084E+01	0.4326E+00	0.3471E-02
Rd 6 E	0.5656E+00	0.1081E+01	0.1019E+01	0.6229E+00	0.2305E-02
Rd 7 E	0.4928E+00	0.9356E+00	0.1339E+01	0.6173E+00	0.7400E-02
Rd 8 E	0.6308E+00	0.1212E+01	0.1046E+01	0.7995E+00	0.2920E-02
Rd 8 W	0.7271E+00	0.1404E+01	0.1058E+01	0.1080E+01	0.1766E-02
Rd 9A E	0.4552E+00	0.8603E+00	0.1074E+01	0.4206E+00	0.3450E-02
Rd 9A W	0.3680E+00	0.6859E+00	0.1014E+01	0.2559E+00	0.4121E-02
Rd 9B E	0.4854E+00	0.9208E+00	0.1031E+01	0.4607E+00	0.2909E-02
Rd 9B W	0.4638E+00	0.8776E+00	0.1062E+01	0.4321E+00	0.3284E-02
Rd 10 E	0.3870E+00	0.7240E+00	0.1095E+01	0.3069E+00	0.4486E-02
Rd 10 W	0.4295E+00	0.8090E+00	0.1105E+01	0.3838E+00	0.3952E-02
Rd 11A E	0.4408E+00	0.8316E+00	0.1004E+01	0.3680E+00	0.5120E-02
Rd 11A W	0.5315E+00	0.1013E+01	0.1009E+01	0.5432E+00	0.2461E-02
Rd 11B E	0.3841E+00	0.7182E+00	0.1301E+01	0.3590E+00	0.6400E-02
Rd 11B W	0.4616E+00	0.8733E+00	0.1024E+01	0.4128E+00	0.3076E-02
Rd 12 E	0.4988E+00	0.9476E+00	0.1058E+01	0.5002E+00	0.2953E-02
Rd 13A E	0.4228E+00	0.7955E+00	0.1045E+01	0.3514E+00	0.3613E-02
Rd 13W	0.5588E+00	0.1068E+01	0.1076E+01	0.6421E+00	0.2617E-02
Rd 14 E	0.3411E+00	0.6322E+00	0.1095E+01	0.2362E+00	0.5341E-02
Rd 14 W	0.3730E+00	0.6960E+00	0.1074E+01	0.2789E+00	0.4542E-02
Rd 16 E	0.6094E+00	0.1169E+01	0.1070E+01	0.7620E+00	0.2297E-02
Rd 16 W	0.6045E+00	0.1159E+01	0.1064E+01	0.7454E+00	0.2297E-02

*NOTATION: DRAIN CAPTY = Discharge (m^3/s); ADJ. SLOPE = Adjusted Slope (m/m)

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