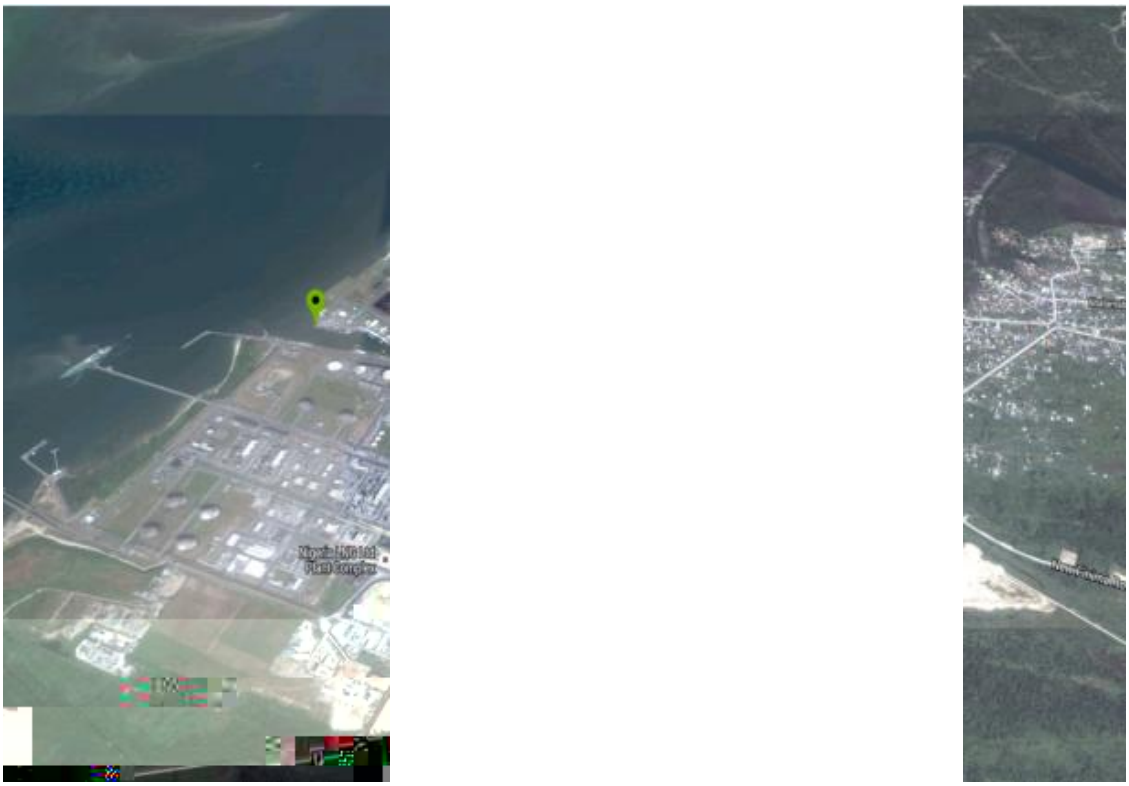
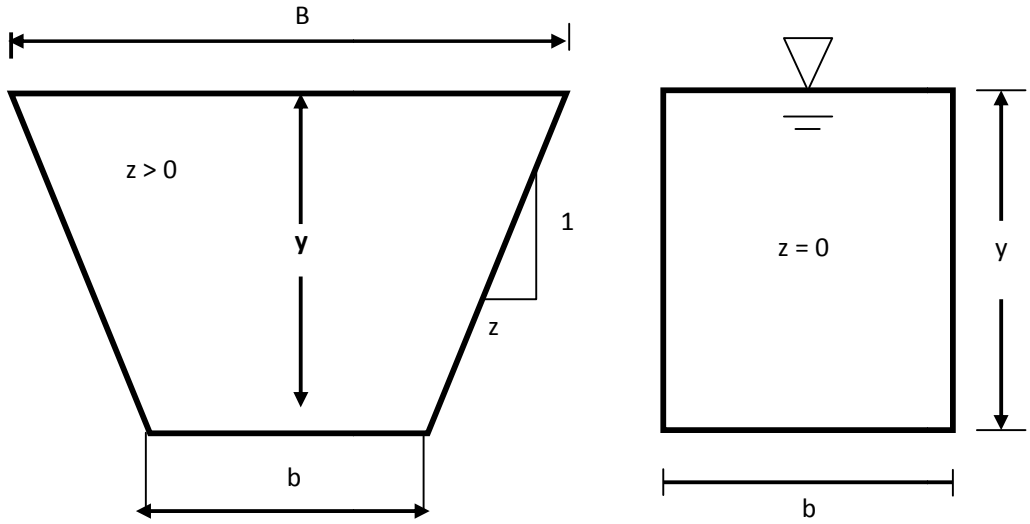


Fig. 1. Map of study area, Bonny Estate with road networks and side drains
Source: Google [3]



(i) Trapezoidal channel (ii) Rectangular channel

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

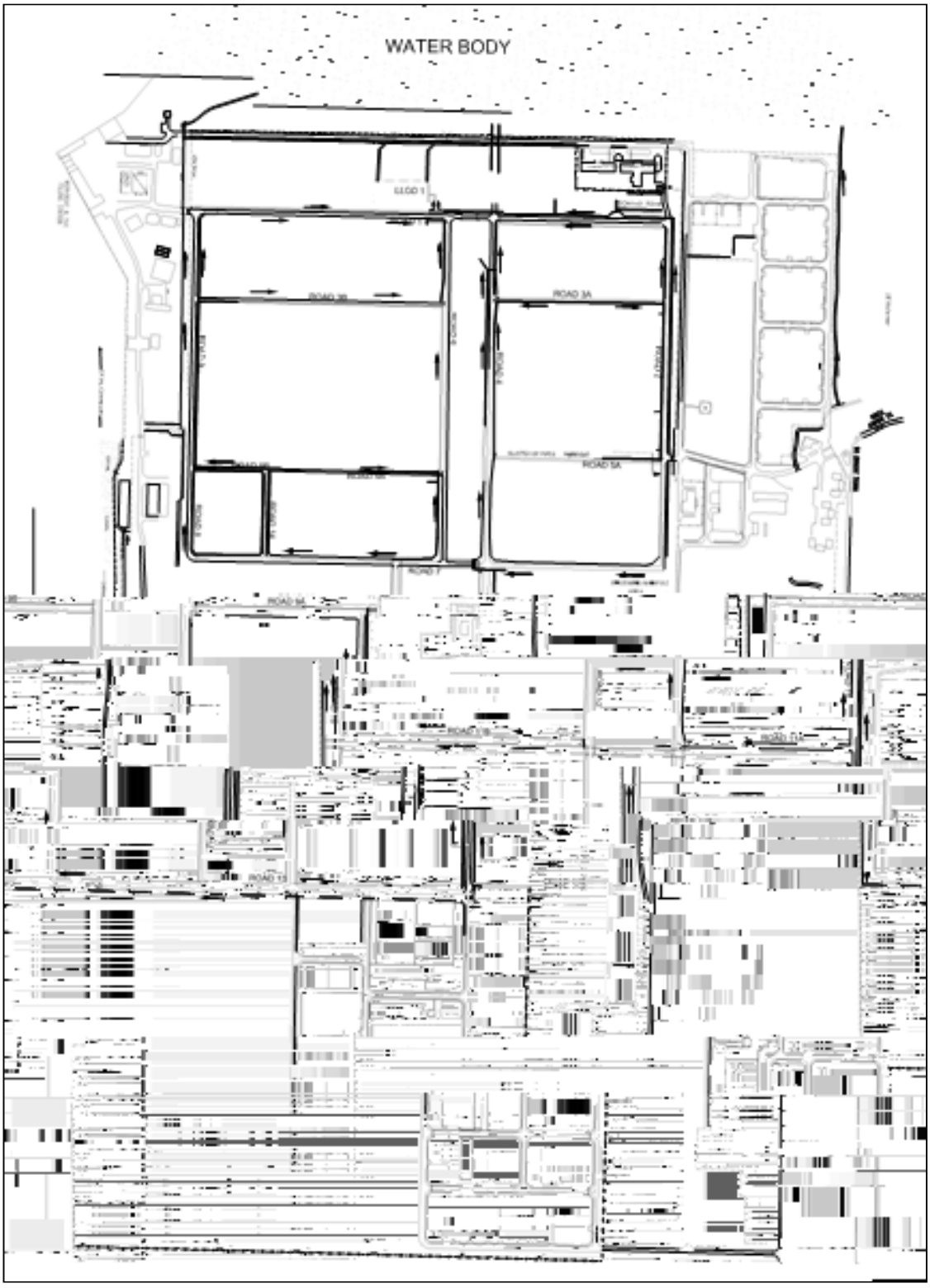


Fig. 3. Existing road network of drains and flow directions

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

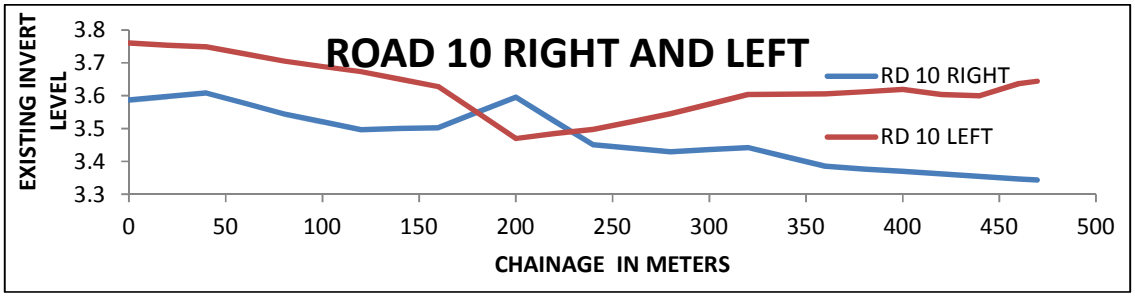


Fig. 8. Drain profiles for road 10, E & W

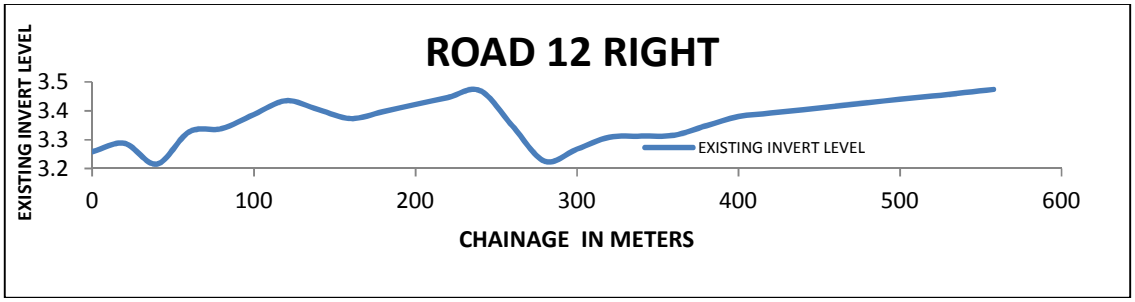


Fig. 9. Drain profile for road 12, E

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

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

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

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

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 ≥ 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 ≤ 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

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					