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Application Of Grumbel Locality Constants And Empirical Approach In Estimation Of Rainfall Intensity For Drainage Design

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***Abstract:** An enhanced drainage system was designed for college of Engineering and Engineering and Engineering Technology, Michael Okpara University of Agriculture, Umudike using rainfall intensity determined with the aid of Grumbel locality constants and empirical method.Reconnaissance survey of the study area was carried out to ascertain the nature of the terrain and length of roads and drains.These were used to determine areas contributing runoff to the drains as well as the required depth and bottom width of the drains. Results of the hydraulic design of the drains showed that a well-channeled trapezoidal drain was more hydraulically efficient than a rectangular shaped drain.*

***Keywords:** Empirical method, Grumbel locality constants, Rainfall intensity, Reconnaissance survey, runoff. trapezoidal channels.*

I. INTRODUCTION

Rain was considered as a gift of nature that, watered agricultural fields, replenished springs, fed streams and rivers, supported game and fish, and made travel through the sea possible throughout the history of man [1].But as urbanization set in, our relationship with rain changed from that of friend to an enemy [2]. When rain falls, a part of it is intercepted by vegetation, some of it is stored in depression on the ground surface, this is called depression storage, which later infiltrates or evaporates. Some of the precipitation is absorbed by the soil, the amount of which depends upon the soil moisture conditions existing at the time of precipitation [3]. If the rain continues further, the water starts infiltrating into the water table, and if the rate of rainfall or the rate at which the water is reaching the ground (p) exceeds the infiltration rate (f), then this excess water starts collecting on the surface, as surface detention, and this water flows overland and joins the streams, rivers, lakes, oceans etc. This flow is known as surface runoff. The water which percolates without joining the water table, and then joins the streams as sub-surface flow, is known as sub- surface flow and is considered as part of surface runoff [4].

Dahigaonkar et al [5] opined that as the process continues, the water that percolates to the ground water table, and later after long periods joins the rivers or streams, is known as ground water flow or base flow

Drainage refers to the disposal of excess water on land before they have entered the stream [6].Drainage is distinguished from flood control which is the prevention of damage from the overflow of natural streams. Drainage may be classified into municipal drainage, land drainage and highway drainage [6].Toxic chemicals and excessive nutrients resulting from a combination of stormwater runoff, point and non-point leaching and groundwater discharges has contributed to surface water pollution which has become an issue of environmental concern worldwide [7]. Pollution resulting from stormwater has been attributed to the process of industrialization and urbanization that has progressively developed over time without any regard for environmental consequences [8].The deterioration of physical, chemical and biological properties of surface water has therefore being observed as a result of this development [9]. The US Environmental Protection Agency (USEPA) estimated that about 30 percent of known water pollution in the united states of America In the United States of America is attributable to stormwater runoff [10]. Large peak floods usually have impact

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on man and his property [11].For proper utilization of rivers' and streams' potential for recreational and aesthetic benefits, it is necessary that the stormwater flowing into such rivers and streams must be properly channelled from road pavements and parking lots [12].Owing to the fact that water is a vital and finite resource necessary for maintaining good health and sanitation, food security and ecological system, it is necessary to manage our urban stormwater so that it does not constitute danger to the sustainability of water source [13].

Thus, the management of stormwater through effective and efficient conveyance systems in urban areas is necessary to minimize flood damages or traffic hazards. Proper management of stormwater will also help in curbing physical, chemical and biological impacts of flood to receiving water bodies. In meeting these objectives of maintaining a healthy and sound environment that promotes academic excellence, this study is thus aimed at the design of an enhanced drainage system for College of Engineering and Engineering Technology (CEET), Michael Okpara University of Agriculture Umudike (MOUAU) which has hitherto constituted problems mainly during periods of heavy rainfall.

Figure 1: Map of Abia state showing Umudike

II. RESEARCH METHODOLOGY

A. DESCRIPTION OF THE STUDY AREA

Michael Okpara University of Agriculture Umudike (MOUAU) is located in Ikwuano Local Government Area of Abia State. Umudike Abia State, lies on latitude 5.4758° North of the Equator and on longitude 7.55° East (Figure 1).Rain falls between the months of February to November. But the onset (substantial rainfall) is during the months of March-September and sharp decrease in amount of rainfall is during the month of October-November. The mean annual temperature is 24^0C–27^0C, whereas the annual rainfall varies between 1500mm and 3500mm. The mean relative humidity is over 75%.

B. RECONNAISSANCE SURVEY

Reconnaissance survey map of the affected areas was carefully carried out and studied but the design was limited to roads/drainage sections where there are no drains as well as where the existing drains were not hydraulically efficient to accommodate the volume of runoff. The essence of reconnaissance survey is to know the actual location of some physical features such as shoulder of the road, gradient of the area e.t.c. These were taken into consideration to provide a better understanding of the storm water flow direction which also helped in determining the slope which is a vital parameter in the drainage design. With the help of the reconnaissance survey, the nature and condition of the existing drains were ascertained.

Many functioning drains have been completely silted, some over-grown by weeds thereby reducing their hydraulic efficiency. Consequently, new drains were proposed to follow the network of roads within the study area.

C. DRAINAGE AREA AND DRAINS

The entire study area was divided into sections based on location and flow characteristics for easy analysis and data collection based on flow characteristics and topographic map. The land use of the catchment such as building, roads, grasses, forest etc was obtained through field survey and measurements.

D. RUNOFF COEFFICIENT

Estimating the runoff coefficients for stormwater flow in a given area depends on the level of imperviousness (built and un-built areas), paved and unpaved roads, forest and grasses.The value of runoff coefficients used in this study was in accordance with [3].

E. RAINFALL INTENSITY

The design rainfall is characterized by its intensity and duration. The rainfall intensity is often read from an intensity-duration curve. This is, however, possible if both the duration T_c and the storm return period T_r are known. The return period can be determined by using Grumbel frequency analysis method or be selected entirely based on the extent of damage anticipated if the flood is exceeded. The return periods is selected 2 to 5 years, if damage due to flooding is small, and from 10 to 100 years when the damage is great. Example of greasy damage include when basements in commercial areas can be flooded [14]. A typical frequency return periods of storm sewers for different districts are shown in figure 3.

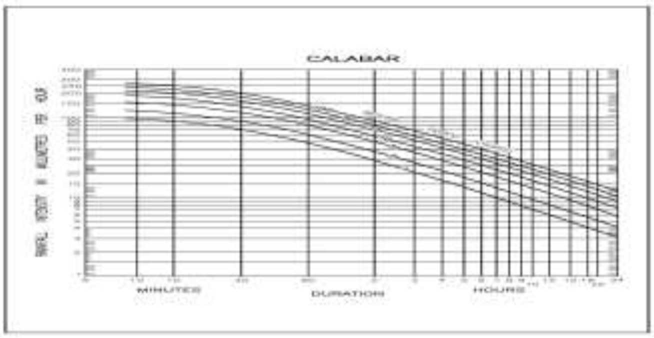

Figure 3: Intensity-Duration-Frequency Curves For Port Harcourt, Calabar And Umudike

The time of concentration (t_c) and rainfall intensity may be computed using Izzard method [15].

$$t_c = \frac{526423bL^{\frac{1}{3}}}{(Ci)^{\frac{1}{3}}} \quad (1)$$

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The coefficient b in the equation is expressed by

$$b = \frac{2.8x10^{5}\, iCr}{(s)^{\frac{1}{3}}} \quad (1a)$$

The parameter C_r is the retardance coefficient with values of 0.007 for smooth asphalt surface, 0.012 for concrete pavement, 0.017 for Tar and gravel pavement and 0.060 for dense blue grass turf. Obtainaing i using Izzard method [15], equation (1) involves trial and error since T_c is expressed as a function of i.

Empirical relationship between rainfall duration and intensity (I) is given by

$$i = \frac{a}{t+b} \quad (2)$$

Where a and b are locality constants;

a= 1846 and b=3.6 for eastern part of Nigeria.

For values of t >12mins;

$$i = \frac{Co}{t^{s}} \quad (2a)$$

Typical values of s = $\frac{1}{2}$ and C_0 = 446.

Oyebande and Longe [16]., using Grumbel extreme value distribution, obtained another empirical formula given by

$$i = KT^{m}t^{n}{}_{1}^{-1} \quad (2b)$$

Where T is the return period in yrs, t, is the rainfall duration in hrs. And k, m and n_1 are parameters dependent on the regions, as tabulated in table 3.

Regions	Parameters			
	K	M	n_1	n_2
Port Harcourt, Calabar, Umudike	54	0.26	-0.86	-0.36
Warri, Benin	47	0.28	-0.85	-0.38
Lagos, Ikeja, Oshodi	34	0.30	-0.89	-0.47
Oshogbo, Ondo, Illorin, Ibadan	40	0.28	-0.87	-0.51
Makurdi, Enugu	38	0.32	-0.90	-0.48
Bida, Ibadan,Yola	38	0.32	-0.90	-0.52
Lokoja, Minna	32	0.25	-0.90	-0.60
Sokoto, Yelwa	33	0.27	-0.87	-0.61
Kano,Gusau, Zaria, Bauchi, Samaru	33	0.32	-0.88	-0.60
Potiskum, Maiduguri	32	0.30	-0.89	-0.59
Nguru, Kastina	30	0.32	-0.95	-0.64

Source: [16].

Table 3: Locality Constants For Rainfall Intensity Of Different Regions

F. DISCHARGES THROUGH THE DRAINS

The drains are designed with discharge determined using the rational formula. The chosen section must give a capacity Q_c greater than the value designed for. Design capacity of drains is given by the Manning's formula;

$$Q = \frac{AR^{\frac{2}{3}}\sqrt{S}}{N} \quad (3)$$

Where: Q = Design flow in (m^3/s)

N = Manning's coefficient or roughness

A = Area of drainage in (m^2)

R = Hydraulic radius (m)

S = Slope of pipe in (m/m)

Manning's coefficients of roughness for pipes are shown table 4.

G. SIZING OF DRAINS

Stormwater flowing through the drains is to be discharged at various locations into the stream(s). Size of drains and the point of discharge into the receiving streams are to be selected and their peak discharges computed by simple addition of discharges from the sub catchments flowing into the streams. The sizes of the drains should be computed using Manning's equation to determine the maximum flow depth based on an assumed valued of width of say 0.5m, 0.75m and 1.0m as the case might be. Ideally, channel depths should be greater than 300 mm (0.3m). Deeper channel drains also needs to be covered. A proposal was made in [17] that where there is space constraint, assumed width of 0.5 m can be used while where there is high runoff based on gravitational flow, assumed width of 1.0 m can be employed. The square drains should fall within the range of assumed width 0.5m and assumed depth of 1.0 m is more economical.

III. RESULTS AND DISCUSSION

A. DESIGN APPROACH

Though different methods may be used in the design of drainages, the one adopted here, is that presented by Chow [18].

The steps are as follows;

- ✓ Estimate N and S, compute the section factor $AR^{2/3}$ from

$$A(R)^{\frac{2}{3}} = \frac{NQ}{\sqrt{S}} \quad (4)$$

Substitute in the equation the expression for A and R and solving for the depth. For rectangular section, $\mathbf{A = 2y^2}$ and $\mathbf{R = \frac{y}{2}}$. For the best trapezoidal section

$$\mathbf{A = y^2} \text{ and } \mathbf{R = \frac{y}{2}}. \quad (4a)$$

- ✓ The capacity of a channel to discharge flood increases with increase in the hydraulic radius or with the wetted perimeter. Hydraulically, the section having the least wetted perimeter for a given area has the maximum discharging capacity. Such a section is called the best hydraulic (economic) section. Channels are designed for the best hydraulic section and modified for permeability.
- ✓ If there are unknowns such as width and side slope of a trapezoidal section assume the values of these and solve for the depth. Several combinations can be found and the final dimensions chosen on the basis of hydraulic efficiency and practicability.
- ✓ Check whether the minimum velocity is satisfied.
- ✓ Add a proper freeboard to the depth of the channel section.

a. DESIGN OF THE MOST ECONOMICAL SECTION

In the design of most economic section of a lined channel, cross- section of lined channel, the hydraulic radius R, should be a maximum. Theoretically, a semi-circular section is the

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best section for an open channel such as the drainage under consideration. However, it is not practical to adopt this section from practical considerations, a trapezoidal or triangular shaped section is usually considered.

b. TRAPEZOIDAL SECTION

For the lined channels with a discharge greater than 85 comics, a trapezoidal section is adopted as shown in figure 4.1. The radius of the corners R, is equal to the depth D. the angle subtended at at the water surface by the corner is equal to ϴ.

The geometrical properties of the section are below;

Area of the channel A, is given by

$$A=BD+\frac{\pi D^2(2\theta)}{2\pi}+2\left(\frac{1}{2D^2\cot\theta}\right) \qquad (5)$$

$$A = BD + D^2(\theta+\cot\theta) \qquad (6)$$

The wetted perimeter,

$$P = B+2D(\theta+\cot\theta) \qquad (7)$$

For drains with side slope of 1:1, ϴ= $45^{0,}$ B = b (bottom width), and D = y (depth)

Area,

$$A = 1.785y^2 \qquad (8)$$

Wetted perimeter,

$$P = 3.570y \qquad (9)$$

Their design parameters are tabulated as shown below;

c. AREAS CONTRIBUTING RUNOFF TO THE EXISTING DRAINS

Areas contributing runoff to the existing drains as obtained from reconnaissance survey carried out on the drains.

Area, A = road length x width. These areas are computed and tabulated as shown in table 4.

Road	Drain	Length (m)	Width, (m)	Area, A(m^2)	Nature of Surface	Shape of drainage
A	01-02	539.7	7.2	3885.84	Finished concrete	Rectangular
	02-03	509	7.2	5076	Finished concrete	Rectangular
	05-06	509	7.2	5076	No drain	
	06-07	539.7	7.2	3911.76	Finished concrete	Rectangular
B	04-16	1537.9	7.2	11072.88	No drain	
	16-17	1537.9	7.2	11072.88	Finished	Rectangular
	08-10	183.9	7.2	1324.08	No drain	
	15-16	183.9	7.2	1324.08	Finished concrete	Rectangular
C	10-11	1257.3	7.2	9052.56	Finished concrete	Rectangular
	13-14	1257.3	7.2	9052.56	Finished concrete	Rectangular
	08-09	1865.5	1865.5		Finished concrete	Rectangular

Table 4: Areas Contributing Runoff

Adopting a trapezoidal channel for these drains, with angle of 45^0 or side slope 1:1, area A, perimeter, P and the hydraulic radius, R, are given in table 5.

d. DESIGN OF THE DRAINS

From eqn 2a, the rainfall intensity using a rainfall duration t,=5 minutes

$i = \frac{a}{t+b} = \frac{1846}{5+3.6}$ = 220mm/hr = $6.11x10^{-5}$m/s.Using equations 2 and 3 and substituting the values of N and S,we obtain the computed values of sides, flow velocities and drain capacities as shown in table 5.

Drainage Section	Area, A A=1.785y^2 $(m)^2$	Perimeter P =3.570y (m)	Hydraulic Radius, R = $\frac{A}{P}$ (m)	Flow Velocity V=$\frac{Q}{A}$	Channel, Velocity V=$\frac{R^{2/3}}{N}\sqrt{S}$ (m/s)	Drain Capacity Q_c= AxV (m^3/s)	Time of concentration t_c
01-02	0.286	1.423	0.201	0.374	0.452	0.129	156.37
02-03	0.286	1.423	0.201	0.225	0.452	0.129	149.43
05-06	0.286	1.428	0.201	0.225	0.452	0.129	149.43
06-07	0.286	1.423	0.201	0.374	0.452	0.129	156.37
04-08	0.446	1.785	0.250	0.502	0.832	0.371	350.10
16-17	0.446	1.785	0.250	0.502	0.832	0.371	350.10
08-10	0.875	2.499	00.350	0.373	0.760	1.303	68.23
15-16	0.875	2.499	00.350	0.373	0.760	1.303	68.23
08-09	2.570	4.280	0.600	1.102	0.937	2.408	299.80
10-11	0.446	1.785	0.250	0.554	0.523	0.233	299.80
13-14	0.446	1.785	0.250	0.554	0.523	0.233	409.23

Table 5: Computed Values Of Sides, Flow Velocities And Drain Capacities.

IV. CONCLUSION

This paper presents a pragmatic approach to an enhanced design of drainage system using college of Engineering and Engineering Technology (CEET), Michael Okpara University of Agriculture Umudike as a case study. The rationale behind this is to prevent environmental degradation that may result from poor drainage design with a view to providing an aesthetically pleasing environment suitable for academic excellence.

V. RECOMMENDATIONS

Owing to the result of this study, the following recommendations are made:

- ✓ Regular and adequate desilting of the drainage system is required inorder to avoid blockage of the drains.
- ✓ Proper maintenance of drainage systems will enhance the efficiency of the drains.
- ✓ Planting of grasses and trees along the adjoining areas to improve flow velocity and reduce soil erosion and sedimentation.

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