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RUNOFF MODELLING AND DRAIN-SIZING SOFTWARE – KNUST DRAINDESIGN

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ABSTRACT:

KNUST DrainDesign is a software that has been developed using Microsoft Visual Basic.NET and its data are stored in Microsoft Access. The rational formula is used to model the runoff while the Manning's equation based on the best hydraulic section is used to ensure optimal performance of drains designed. The software is equipped with facilities that makes it extremely user friendly. It prompts the user for data where required, gives warnings and advice on seemingly 'suspicious' values and permits one to key in only expected characters. KNUST DrainDesign also incorporates both Imperial and SI units. It is able to design several shapes of channels with relative ease.

Keywords: Drain design, software, runoff, rational formula, and Manning's formula

1. INTRODUCTION

Engineering softwares provide fast and reliable means for analysing and designing engineering phenomena and structures. The problem with these softwares, however, is that they are often complex and difficult to use. One needs to have used these softwares several times in order to master the required processes involved. Most of the times, these softwares require in-depth technical knowledge and extreme care in their application. In Ghana, the use of such softwares is gaining widespread recognition. There is a dearth, however, when it comes to the use of constants and required formulae in these applications as most of these softwares are not designed with our environment in mind. Hence, locally developed softwares which incorporate the local conditions in their conceptualisation and development will be invaluable (Abban, 2003).

In view of the above, the Civil Engineering Department of the KNUST is seeking to develop several softwares to ensure the incorporation of local conditions. A typical area of specialisation that will benefit from such developments is drain sizing for runoff management. The design process of sizing drains for stormwater is an arduous and relatively time consuming one when done manually. This is because several factors have to be considered when designing the drain system. The amount of work done and the time spent in drainage design can however be reduced by the use of computer software. Spreadsheets like Microsoft Excel can be used to simplify the design process, however these are customized and do not provide guides and user-friendly controls for all users. As a result, a software known as ***KNUST DrainDesign***, is being developed by the Water Resources Division of the Department of Civil Engineering to simplify the design process and ensure that drain designers benefit from this product by reducing the time required and reducing the tendency of committing avoidable errors. This paper presents the preliminary outcome of KNUST DrainDesign.

The process of designing drains involves a series of steps. The Rational formula is first used to estimate the runoff expected from precipitation. This formula requires the rainfall intensity, the catchment area, and the runoff coefficients based on characteristics of the catchment. The catchment area is determined from the topographical map and the coefficients are determined from literature based on the existing characteristics of the catchment. A return period and time of concentration are required before the rainfall intensity can be determined. In Ghana, the J. B. Dankwa Intensity-Duration-Frequency curves (Dankwa, 1972) are used to determine rainfall intensities for given return periods and times of concentration. For programming purpose, the curves for various major locations in Ghana have been fitted with equations and these equations have been incorporated in the KNUST DrainDesign software with the required constants. The Manning's formula is then used to determine adequate channel sections. Various hydraulic equations are used to check flow properties of the selected channels and the user can alter the channel properties to ensure optimal performance. This paper which is a result of the development of the KNUST DrainDesign software discusses the software, its features and the drain design process.

For maximum benefits to the user, the next step is the development of a simple user manual that will enable users get acquainted with the software within a minimum time.

2. Drain Design Process

The design of drains can be considered to be made up of two main parts. The first part being the estimation of runoff and the second consisting of the hydraulic design of the channel.

There are several methods used to estimate runoff. Some of these are infiltration methods, the unit hydrograph method, the rational method, empirical formulae and tables etc. Outstanding among these are the unit hydrograph method and the rational method which have gained popularity among engineers. KNUST DrainDesign is based on the rational method because of the fact that it is simple to use and ensures safe designs, and most of all it is the commonest method used in Ghana.

Manning's equation is used for the hydraulic design of the channel. Other considerations such as hydraulic best sections, channel material, acceptable velocities etc, are also taken into account during the design of the channel.

2.1 Rational Method

The rational formula can be taken as representative of many empirical or semi-empirical formulae which represent the relation between rainfall and peak runoff. Although the formula is based on a number of assumptions which cannot be readily satisfied under actual circumstances, its simplicity has won it popularity (Butler and Davies, 2000).

Butler and Davies (2000) also mention that the origin of the formula is somewhat obscure. They discuss that in American Literature, the formula was first mentioned by Kuichling in 1889 for determination of peak runoff for sewer design in Rochester, New York; while some authors believe that the principles of the formula were explicit in the work of Mulvaney in1851. In England however, the rational method is often referred to as the Lloyd-Davis method owing to the implication ascribed to a paper in 1906 (Chow, 1964). The rational formula is given by:

$$q = 0.278CIA \qquad (1)$$

where q = the peak runoff (m³/s), C = the runoff coefficient dependent on the characteristics of the drainage basin, I = the rainfall intensity (mm/hr), A = the drainage area (km²).

A number of assumptions are made when using the rational formula. First of all, it is assumed that the maximum rate of flow, owing to certain rainfall intensity over the drainage area, is produced by that rainfall which is maintained for a time equal to the period of concentration of flow at the point under consideration. It is also assumed that an equal amount of runoff will be generated for storms of the same intensity once they occur over the same catchment areas. Finally, the formula is assumed to be valid for areas of up to 2km². Beyond that, an area reduction factor, whose value is dependent on the catchment area, should be applied to the formula.

C in the formula can be obtained from literature and it depends on the nature of the catchment. 'A' is usually obtained from the topographical map of the catchment using a planimeter or approximate polygons. 'I' can be determined in a number of different ways: either from charts or by the use of empirical formulae. In Ghana, they are usually determined using Intensity-Duration-Frequency (I-D-F) curves developed by J. B. Dankwa (1972). In an earlier unpublished research work for Ghana, Jehanfo (1999) fitted these curves with the equations

$$I = \frac{a}{(b+t_c)^c} \qquad (2)$$

Where I = the rainfall intensity (mm/hr), t_c = the time of concentration (hrs), a, b and c = constants dependent on the return period and locality.

The constants a, b and c were generated for all the J. B. Dankwa I-D-F curves, thus providing a fast and accurate method for the determination of the rainfall intensity. Time of concentration may be defined as the time taken for a drop of water to travel from the most remote part of the catchment to the outfall and can also be determined from the map using the Lloyd-Davis formula. The return period is the likelihood of a rain of a given intensity occurring within a period of time. This is selected based on astute engineering judgement. When C, I and A have been obtained, equation (1) can then be use to compute the expected runoff. Equations (1) and (2) are both incorporated in the KNUST DrainDesign software for runoff and rainfall intensity estimation, respectively.

2.2 Hydraulic Considerations

The second part of the design can be carried out once the runoff has been estimated. This is the hydraulic design of the channel which will convey the runoff to the outfall. For the hydraulic design of the channel, Manning's equation is used. The equation is given by

$$Q = \frac{1}{n} AR^{2/3}S^{1/2} \qquad (3)$$

Where Q is the expected discharge (m³/s), A is the cross-sectional area of the section (m²), R is the hydraulic radius (ratio of cross-sectional area to the wetted perimeter of the section) (m), and S is the longitudinal slope of the channel.

Hydraulic best sections of the channels being designed are also taken into account during the design. These are the sections which characterize the maximum possible average velocity and therefore the wetted perimeter, hence a maximum discharge. KNUST DrainDesign is equipped with features that enable one to select the hydraulic best section for a given cross-section. For a hydraulic best section, with depth h (Featherstone and Nalluri, 1995; Hederson, 1966)

$$\frac{dP}{dh} = 0 \qquad (4)$$

where P is the wetted perimeter.

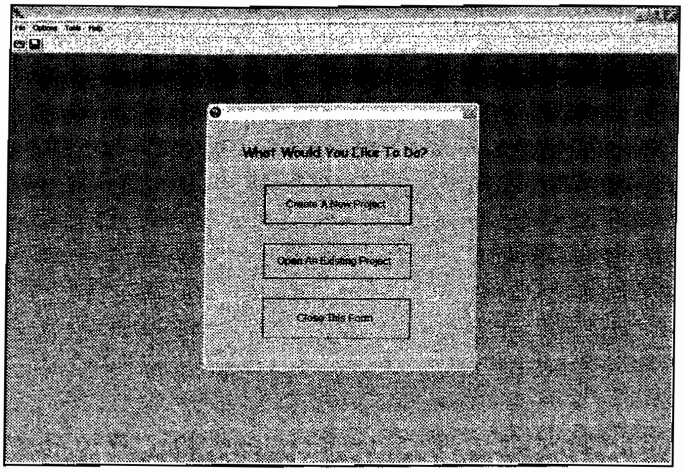
Appropriate manipulations and substitutions are made and appropriate channel dimensions are obtained. These dimensions are then verified to ensure that water velocities and discharges are within acceptable limits.

3. THE SOFTWARE

KNUST DrainDesign is developed using Microsoft Visual Basic.Net (Petroutsos, 2002) and is based on the design process outlined above. Its data is stored in Microsoft Access. Figure 1 displays the window which pops up when the program is started.

On start-up, the software has dialog boxes, all similar to the one seen in Figure 1, that guide the user to the appropriate form on which the desired design can be carried

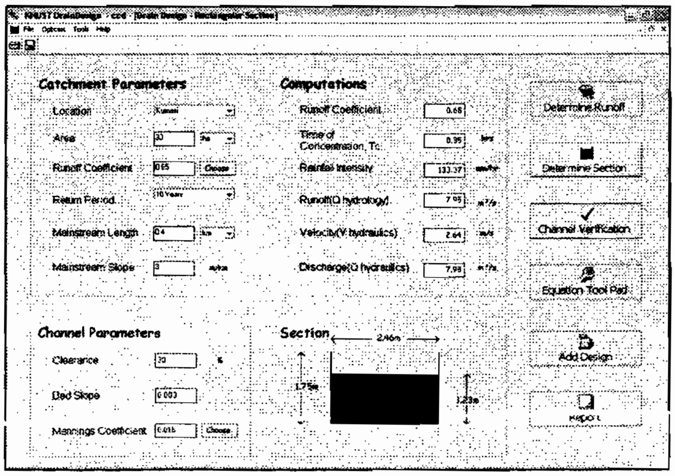
Figure 1 Start-up window which pops up when the program is started



out. At present the software can be used to design five different kinds of channel cross-sections: rectangular, trapezoidal, triangular, circular and U-shaped cross-sections. Each cross section has an independent form on which the design is carried out. Figure 2 shows a typical form used to design rectangular channels. This window will be used for most of our illustrations.

The software has been furnished with constants for the rainfall intensity equation for all the major towns in Ghana as was presented by J. B. Dankwa. The designer only has to choose a location and a return period from the catchment parameters group box and the constants for the particular location and rainfall intensity will be calculated by the software. Provision has been made in the tools menu for updating and editing the rainfall intensity constants. This will be useful if the curves are revised. Parameters that are required for the design are handled in the catchment parameters and channel parameters group boxes.

Figure 2 Typical form used to design rectangular channels



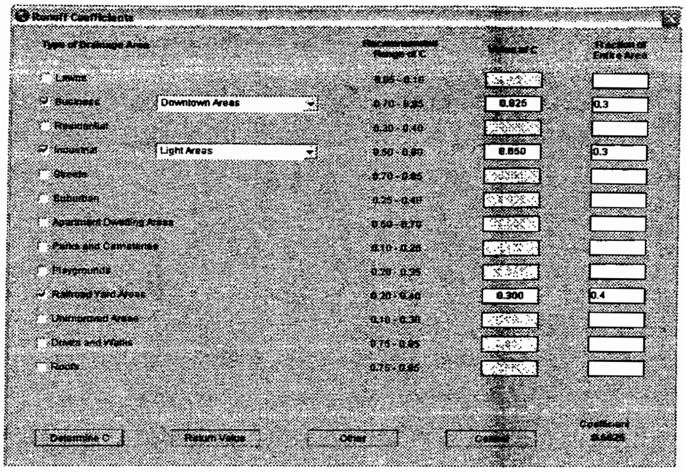
Location: Kumasi
Area: 30 ha
Runoff Coefficient: 0.65
Return Period: 10 Years
Mainstream Length: 0.4 km
Mainstream Slope: 3 m/km

Runoff Coefficient: 0.65
Time of Concentration, Tc: 0.35 hrs
Rainfall Intensity: 133.37 mm/hr
Runoff(Q hydrology): 7.95 m³/s
Velocity(V hydraulics): 2.64 m/s
Discharge(Q hydraulics): 7.93 m³/s

Clearance: 30 %
Bed Slope: 0.003
Mannings Coefficient: 0.016

The runoff and Manning coefficients have also been included in the software. Depending on the nature of the catchment surface and the channel material, appropriate constants may be chosen from a pool of constants. Figure 3 shows the form from which one may select or compute runoff coefficients.

Figure 3 Form for computing runoff coefficients



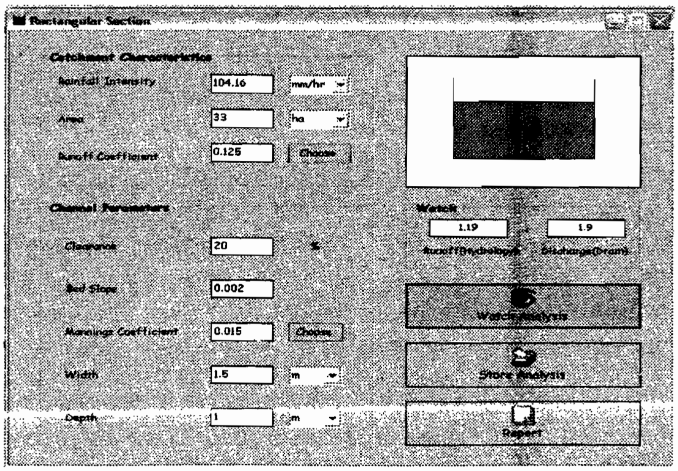
Type of Drainage Area		Recommended Range of C	Value of C	Fraction of Entire Area
☐ Lawns		0.05 - 0.10		
☑ Business	Downtown Areas	0.70 - 0.95	0.825	0.3
☐ Residential		0.30 - 0.40		
☑ Industrial	Light Areas	0.50 - 0.80	0.650	0.3
☐ Streets		0.70 - 0.95		
☐ Suburban		0.25 - 0.40		
☐ Apartment Dwelling Areas		0.50 - 0.70		
☐ Parks and Cemeteries		0.10 - 0.25		
☐ Playgrounds		0.20 - 0.35		
☑ Railroad Yard Areas		0.20 - 0.40	0.300	0.4
☐ Unimproved Areas		0.10 - 0.30		
☐ Drives and Walks		0.75 - 0.85		
☐ Roofs		0.75 - 0.95		

Coefficient: 0.5625

After the necessary data for the catchment is entered, the runoff can be computed by clicking the 'Determine Runoff' button which can be seen in Figure 2. The software does the necessary computations and returns the required data in the computations group box. Based on the runoff, the designer may select appropriate parameters for the channel and go on to determine the channel dimensions by clicking on the 'Determine Section' button. Again, the necessary computations are carried out and hydraulic best section of the channel is drawn in the sections group box giving dimensions.

The velocity and discharge of the section are also displayed in the computations group box. The engineer may decide to use dimensions other than those displayed. In this case, the channel verification feature may be used to ascertain the veracity of the chosen dimensions. The channel verification button can be found on each drain form. Figure 4 shows a typical channel verification window for a rectangular channel.

Figure 4 Typical channel verification window for a rectangular channel



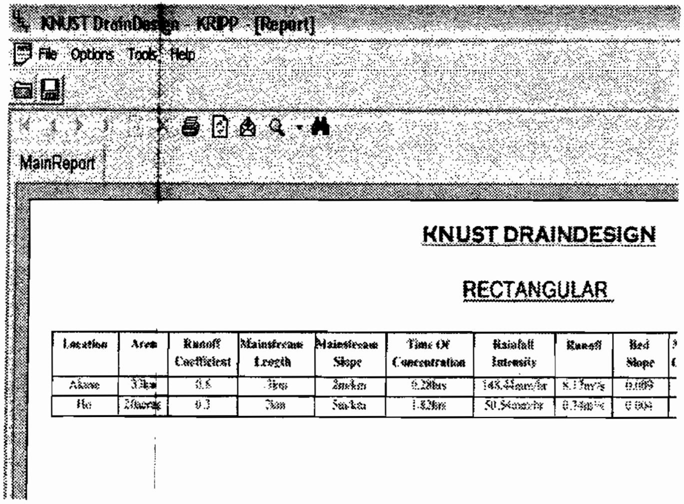
Rainfall Intensity: 104.16 mm/hr
Area: 33 ha
Runoff Coefficient: 0.125

Clearance: 20 %
Bed Slope: 0.002
Mannings Coefficient: 0.015
Width: 1.5 m
Depth: 1 m

Runoff(Hydrology): 1.19
Discharge(Drain): 1.9

The equation tool pad feature acts like a customized calculator. It has been provided with a number of equations found in hydrology and hydraulics. It is used to predict unknown values when all other parameters are given. For instance, if the runoff, catchment area and runoff coefficient are known, the equation tool pad may be used to calculate the rainfall intensity. This is an added feature which may come in handy from time to time. Finally, after designing a number of drains it becomes necessary to prepare a report on all the designs that have been carried out. Upon adding a number of designs to the project a report may be generated. The report displays all the important information used in the designs. Figure 5 shows a portion of a typical report window.

Figure 5 Portion of a typical report window



KNUST DRAINDESIGN

RECTANGULAR

Location	Area	Runoff Coefficient	Mainstream Length	Mainstream Slope	Time Of Concentration	Rainfall Intensity	Runoff	Bed Slope
[illegible]	[illegible]	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4. SOFTWARE EVALUATION

Designs produced by the software were compared with designs from various Civil Engineering Firms in Ghana. Raw data for catchments were obtained from these Civil Engineering Firms and these were analysed using both the software and excel spreadsheets. The results given by the software were then compared with those of Excel and those of the firms and the aberrations were noted. It may be noted from the Tables below that in all cases there were only slight variances in the time of concentration and the rainfall intensities.

Tables 1 through 3 show summary results of comparison of some data analysed in the study. In each Table, the percentage differences between time of concentration, t_c, rainfall intensity, I, and runoff, q, have been determined. Table 1 shows a comparison between manual computations by the firms and computations by the software. Table 2 shows comparison between the manual computations and computations done in Excel, while Table 3, comparison between computations done in Excel and those by the software.

4.1 Discussion of Analysis

Data from the Tables above are only a portion of data that were obtained and analysed and are selected to give a fair representation of the analyses.

From Tables 1 and 2, it can be noted that the percentage difference between the rainfall intensities read by engineers and those computed by the software are all below 5. The difference for the time of concentration, however, has a small number above 5%. In the case of the runoff however, the percentage difference ranges between 0 and 10% with most below 7%. One reason is that runoff and time of concentration values are rather small and slight variations produce relatively high percentage difference. Another explanation that may be offered for the relatively high differences is the human factor. No matter how meticulous one may be, one is likely to make errors. Also, due to the arduous and tedious nature of the drain design process, chances of making errors are accentuated.

It can also be noted from Table 3 that there were absolutely no differences between computations carried out using Excel spreadsheets and computations carried out by the software in the case of the time of concentration and runoff values. This further abuts the point made in the preceding paragraph on the human factor. In the case of rainfall intensities, there were some very small differences, all of which were below 0.1%. This is due to differences in approximations made by the spreadsheets and the software. These differences are however insignificant.

Tables 4 below shows a comparison between some drain sizes recommended by KNUST DrainDesign and those recommended by practising Civil Engineers. As can be seen in Table 4, KNUST DrainDesign does not suggest standard drain dimensions; rather it suggests sizes obtained directly from computations based on the best hydraulic section. For example, for the u-drain in catchment C4 of Table 4, the software suggests a size of 0.46m×0.91m. In practice, however, standard drain sizes are used and so the next standard size above the suggested size is selected and that is 0.6m×0.9m. As shown in Table 4, this dimension agrees with that suggested by practising engineers using the manual method of design.

In view of this, the KNUST DrainDesign has been provided with *Channel verification* tools so that the efficiency of standard drain sizes chosen by the designer may be assessed. It can be noted from Table 4 that most of the drain sizes recommended by the software are lower than those recommended from manual designs. This implies that the software user only needs to select the next higher standard size for implementation. For the dimensions of circular drains (pipes), the software gives flow depth and a possible diameter as width of the drain. However, in practice there is only one dimension for circular drains: diameter.

5. CONCLUSIONS

This paper has presented a report on a software developed to design drains for stormwater management. The software is being developed by the Water Resources Group of the Department of Civil Engineering at the KNUST therefore called KNUST DrainDesign. It is believed that this software will be of benefit to both students and practising engineers in Ghana. This being the very first version may come with some challenges, however it is hoped that the comments of users improve future version of the software.

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Table 1 Comparison of software and manual computation

Location	drain type	t_{cs}	I_s	q_s	t_{cm}	I_m	q_m	% diff., t_c	% diff., q	% diff., I
Daboya Nyohini Road	u-drain	0.34	110.42	0.89	0.34	107.82	0.84	0.59	5.95	2.41
	u-drain	0.48	93.23	1.37	0.46	94.5	1.4	4.35	2.14	1.34
	u-drain	0.21	131.9	0.31	0.21	128.09	0.31	0.94	0	2.97
	Pipe	0.54	87.36	0.02	0.53	85.6	0.02	1.89	0	2.06
	u-drain	0.54	87.36	0.02	0.51	86.2	0.02	5.88	0	1.35
Industrial Road	Pipe	0.26	122.09	0.99	0.26	119.7	0.93	0	6.45	2.00
	Pipe	0.26	122.3	1.03	0.26	116.56	1.02	0	0.98	4.92
	Pipe	0.33	111.16	0.71	0.31	115.48	0.71	6.45	0	3.74
	Pipe	0.43	99.3	0.07	0.42	100	0.07	2.38	0	0.70
	u-drain	0.47	93.98	0.02	0.42	94.3	0.022	11.90	9.09	0.34
Watherson Link 3	u-drain	0.06	171.64	0.06	0.06	174.3	0.06	0	0	1.52
	u-drain	0.14	147.45	0.27	0.14	134.88	0.26	0	3.85	9.32
Watherson Link 2	u-drain	0.09	162.81	0.12	0.09	166.2	0.11	0	9.09	2.04
	u-drain	0.09	161.99	0.09	0.09	168.2	0.085	0	5.88	3.69
Watherson Link 1	u-drain	0.05	174.87	0.06	0.05	175.2	0.055	0	9.09	0.19
	u-drain	0.08	166.21	0.15	0.08	159.2	0.14	0	7.14	4.40
New Saka Road	u-drain	0.09	163.36	0.57	0.09	160.2	0.55	0	3.64	1.97
	u-drain	0.09	162.88	0.48	0.09	158.2	0.45	0	6.67	2.96
	u-drain	0.12	154.45	0.48	0.12	151.3	0.47	0	2.13	2.08
	u-drain	0.08	167.6	0.37	0.08	160.2	0.35	0	5.71	4.62

Table 2 Comparison of excel and manual computation

Location	drain type	t_{ce}	i_e	q_e	t_{cm}	i_m	q_m	% diff., t_c	% diff., q	% diff., I
Daboya Nyohini Road	u-drain	0.34	110.42	0.89	0.34	107.82	0.84	0.59	5.95	2.41
	u-drain	0.48	93.23	1.37	0.46	94.5	1.4	4.35	2.14	1.34
	u-drain	0.21	131.9	0.31	0.21	128.09	0.31	0.94	0	2.97
	Pipe	0.54	87.36	0.02	0.53	85.6	0.02	1.89	0	2.06
	u-drain	0.54	87.36	0.02	0.51	86.2	0.02	5.88	0	1.35
Industrial Road	Pipe	0.26	122.09	0.99	0.26	119.7	0.93	0	6.45	2.00
	Pipe	0.26	122.3	1.03	0.26	116.56	1.02	0	0.98	4.92
	Pipe	0.33	111.16	0.71	0.31	115.48	0.71	6.45	0	3.74
	Pipe	0.43	99.3	0.07	0.42	100	0.07	2.38	0	0.70
	u-drain	0.47	93.98	0.02	0.42	94.3	0.022	11.90	9.09	0.34
Watherson Link 3	u drain	0.06	171.64	0.06	0.06	174.3	0.06	0	0	1.53
	u drain	0.14	147.45	0.27	0.14	134.88	0.26	0	3.85	9.32
Watherson ILnk 2	u drain	0.09	162.81	0.12	0.09	166.2	0.11	0	9.09	2.04
	u drain	0.09	161.99	0.09	0.09	168.2	0.085	0	5.88	3.69
Watherson Link 1	u drain	0.05	174.87	0.06	0.05	175.2	0.055	0	9.09	0.19
	u drain	0.08	166.21	0.15	0.08	159.2	0.14	0	7.14	4.40
New Saka Road	u drain	0.09	163.36	0.57	0.09	160.2	0.55	0	3.64	1.97
	u drain	0.09	162.88	0.48	0.09	158.2	0.45	0	6.67	2.96
	u drain	0.12	154.45	0.48	0.12	151.3	0.47	0	2.13	2.08
	u drain	0.08	167.6	0.37	0.08	160.2	0.35	0	5.71	4.62

Table 3 Comparison of excel and software computation

Location	drain type	t_{cs} hour	t_{ce} hour	% difference time of concen.	I_s mm/hr	Rainfall intensity I_e mm/hr	% difference Rainfall intensity	runoff software q_s m^3/s	runoff excel q_e m^3/s	% difference runoff
Daboya Nyohini Road	u-drain	0.34	0.34	**0**	110.42	110.399	**0.02**	0.89	0.89	**0**
	u-drain	0.48	0.48	**0**	93.23	93.219	**0.01**	1.37	1.37	**0**
	u-drain	0.21	0.21	**0**	131.9	131.851	**0.04**	0.31	0.31	**0**
	Pipe	0.54	0.54	**0**	87.36	87.352	**0.01**	0.02	0.02	**0**
	u-drain	0.54	0.54	**0**	87.36	87.352	**0.01**	0.02	0.02	**0**
Industrial Road	Pipe	0.26	0.26	**0**	122.09	122.06	**0.02**	0.99	0.99	**0**
	Pipe	0.26	0.26	**0**	122.3	122.26	**0.03**	1.03	1.03	**0**
	pipe	0.33	0.33	**0**	111.16	111.14	**0.02**	0.71	0.71	**0**
	pipe	0.43	0.43	**0**	99.3	99.28	**0.02**	0.07	0.07	**0**
	u-drain	0.47	0.47	**0**	93.98	93.97	**0.01**	0.02	0.02	**0**
Watherson Link 3	u drain	0.14	0.14	**0**	148.5	148	**0.04**	0.19	0.19	**0**
	u drain	0.06	0.06	**0**	171.6	172	**0.06**	0.06	0.06	**0**
	u drain	0.14	0.14	**0**	147.5	147	**0.03**	0.27	0.27	**0**
Watherson Link 2	u drain	0.09	0.09	**0**	162.8	163	**0.05**	0.12	0.12	**0**
	u drain	0.09	0.09	**0**	162	162	**0.05**	0.09	0.09	**0**
Watherson Link 1	u drain	0.05	0.05	**0**	174.9	175	**0.06**	0.06	0.06	**0**
	u drain	0.08	0.08	**0**	166.2	166	**0.05**	0.15	0.15	**0**
New Saka Road	u drain	0.09	0.09	**0**	163.4	163	**0.05**	0.57	0.57	**0**
	u drain	0.09	0.09	**0**	162.9	163	**0.05**	0.48	0.48	**0**
	u drain	0.12	0.12	**0**	154.5	154	**0.05**	0.48	0.48	**0**
	u drain	0.08	0.08	**0**	167.6	168	**0.05**	0.37	0.37	**0**

Table 4 Comparison of drain sizes by different methods

Location	catchment no.	Drain type	size of drain (manual)		size of drain (software)	
			height (m)	width (m)	height (m)	width (m)
Daboya Nyohini Road	c4	u drain	0.6	0.9	0.46	0.91
	c3	u drain	0.9	1.1	0.5	1
	c2	u drain	0.6	0.6	0.32	0.64
	c1	u drain	0.6	0.6	0.22	0.44
	c5	u drain	0.6	1	0.48	0.95
	c6	u drain	0.9	1.2	0.49	0.97
Industrial Road	c8a	Pipe	0.9	0.9	0.55	0.7
	c8b	Pipe	0.9	0.9	0.54	0.8
	c9	Pipe	1.2	1.2	0.96	1.09
	c10	Pipe	0.45	0.45	0.35	0.42
	c10	u drain	1.2	1.2	0.87	1.02
	c10	Pipe	1.2	1.2	0.92	1
	c10	Pipe	1.2	1.2	0.95	1.02
	c10	Pipe	0.45	0.45	0.34	0.4
Watherson Link 3	c15	u drain	0.45	0.45	0.39	0.46
	c14	u drain	0.45	0.45	0.35	0.49
	c16	u drain	0.45	0.45	0.26	0.53
Watherson Link 2	c10	u drain	0.45	0.45	0.23	0.46
	c11	u drain	0.45	0.45	0.19	0.38
Watherson Link 1	c12	u drain	0.45	0.45	0.39	0.39
	c13	u drain	0.45	0.45	0.44	0.48