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Comparing Developed Runoff Coefficients for Some Selected Soils of Gidan Kwano with Exiting Values

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Abstract – *An analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area. Models that describe watershed hydrology are classified according to several criteria. A non-pressure rainfall simulator with a dimension of 22.9m by 2m and adjustable feet with minimum height of 1.5m was used for the research. The five runoff plots were set up to measure surface runoff for the five types of soil under controlled conditions. The plot was established directly in the project area with a slope size of 9%. The various types of soil were determined and excavated where necessary at 20cm depth and replaced with the current type of soil existing within the runoff plots. Based on the available parameters, three runoff equations were considered. The calculated values using the rational formula ranged between 0.01 and 0.026; FAA values ranged between -0.162 and -1.321 while for that of Izzard method, the values ranged between 0.212 and 0.458. It was concluded that if the slope of 6% is maintained the values of runoff coefficient will be the same as those that are in existence.*

Key Words – *Runoff, soil, time of concentration, travel time, lag time, water*

1 Introduction

Surface runoff is part of rainfall which after compensation of evaporation, abstraction, surface detention and infiltration flows over land and concentrates in stream network and finally discharges from the through the main river (Vahabi and Ghafouri, 2009). The transformation of rainfall into runoff over a catchment is a complex hydrological phenomenon, as this process is highly nonlinear, time-varying and spatially distributed (Zakarmoshfegh, *et al.*, 2008). A number of models have been developed to simulate this process. Depending on the complexities involved, these models are categorized as empirical, black-box, conceptual or physically-based distributed models (Rajurkar *et al*., 2002; Singh, 1997: Darbandi, *et al*., 2008; Verbist, *et al*., 2010). Vegetation, especially in the case of forests, plays an important role in regulating runoff, as it reduces dramatically surface water volume, runoff velocity and peak discharge (Chifflard *et al*., 2009). Many studies showed that the variation in runoff is attributed to the vegetation cover and land use management changes. Removal of forest coverage causes important changes in the hydrological balance of a watershed, although the magnitude of the response is highly variable and unpredictable (Shi *et al.*, 2007). Increased forest coverage, replacing pasture areas, can trigger a reduction of annual flow of up to 40% (Zhang *et. al.*, 2009).

The proportion of total rainfall that becomes runoff during a storm event represents the runoff coefficient. In the classical 'rational method' it is considered to be a constant, depending on characteristics of the drainage basin, such as surface cover.

Determination of runoff coefficient is dependent on some parameters such as soil infiltrability, rainfall intensity, slope, antecedent moisture conditions, land use, and soil texture (Sivakumar, *et al.*, 2001). Having the runoff coefficient over different soil types and condition and considering the effective parameters enables users to design various structures within and outside the farm. Most drainage systems concepts need to be addressed properly in order to maintain their efficiency (Abustan, *et al.*, 2008).

The rational method is one of the earliest and best known techniques for estimating peak flows for small watersheds. Despite its age and considerable criticism about its adequacy, it is still widely used for estimating peak flows of small rural watersheds and for urban drainage design throughout the world. Application of the rational method requires estimates of time of concentration (T_c) and runoff coefficient (*C*). In practice, designers always have to use a formula for estimating time of concentration. Numerous empirical formulae for time of concentration have been developed (Sikka and Selvi, 2005).

The primary objective of this study is to develop runoff coefficient for some selected soils in Gidan Kwano area of the Federal University of Technology, Minna, Nigeria and to compare the obtained values with existing values of the coefficient.

2 Materials and Methods

2.1 Study Area

Simulated rainfall studies were conducted on the permanent site farm of the Federal University of Technology, Minna, Gidan Kwano which is known to have a total land mass of eighteen thousand nine hundred hectares (18,900 ha). Located along kilometer 10 Minna – Bida Road, South – East of Minna in Bosso Local Government Area of Niger State. It has a horse – shoe shaped stretch of land, lying approximately on longitude of 06^0 28' E and latitude of 09^0 35' N. The site is bounded Northwards by the Western rail line from Lagos to the northern part of the country and the eastern side by the Minna – Bida Road and to the North – West by the Dagga hill and river Dagga. The entire site is drained by rivers Gwakodna, Weminate, Grambuku, Legbedna, Tofa and their tributaries. They are all seasonal rivers and the commonest among them is the river Dagga. The most prominent of the features are river Dagga, Garatu Hill and Dan Zaria dam (Musa, 2003). Figure 1 shows the extracted map of Minna form that of Niger State and Nigeria while Figure 2 shows the map of the permanent site of the Federal University of Technology, Minna, Nigeria.

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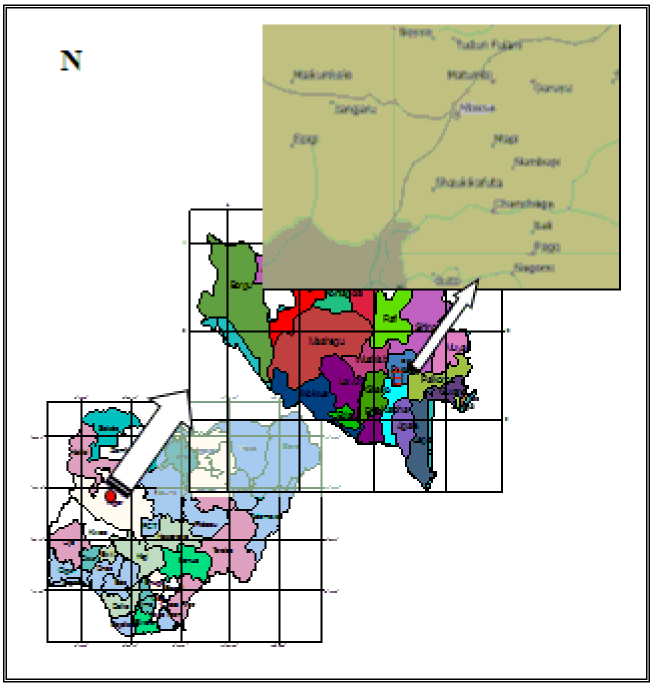

Fig. 1: Extracted map of Minna from Niger State, Nigeria

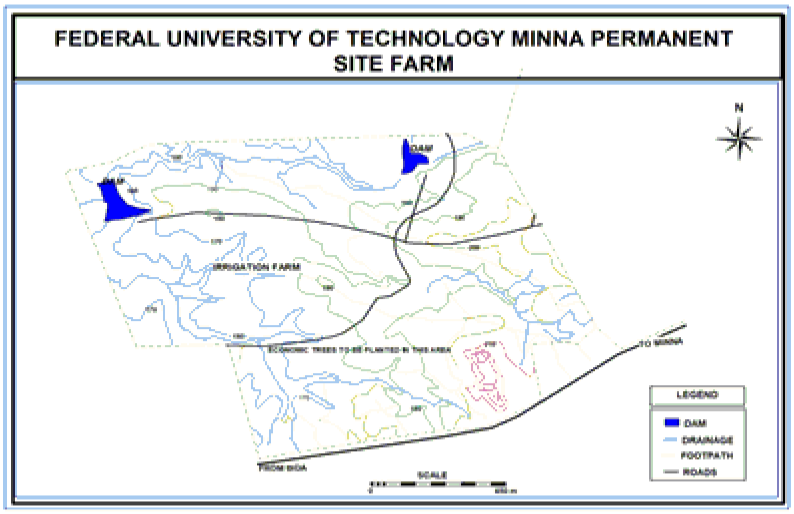

Fig 2: Map of the permanent site farm of the Federal University of Technology, Minna

The major soil found in this area is the sandy loam type with a sparse distinction of the sandy–clay soil and sandy soils. This has so far encouraged the residents of Minna metropolis and neighbouring villager to use the land for agricultural activities such as farming and grazing by the nomadic cattle rearers (Musa, 2003). Figure 3 here shows the soil distribution map of the Permanent site irrigation farm of the Federal University of Technology, Minna.

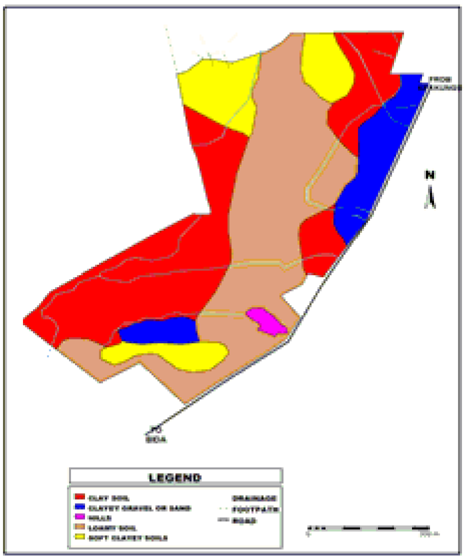

Fig. 3: Soil map of a section of the Federal university of Technology, Minna

A non-pressure rainfall simulator with a dimension of 22.9m by 2m and adjustable feet with minimum height of 1.5m was used for the research. The five runoff plots were set up to measure surface runoff for the five types of soil under controlled conditions. The plot was established directly in the project area with a slope size of 9%. The various types of soil were determined and excavated where necessary at 20cm depth and replaced with the current type of soil existing within the runoff plots. The soils were then ramped to the initial bulk density measured in the field.

Care was taken to avoid study areas with special problems such as farmlands, rills, cracks, or gullies crossing the plot. These would drastically affect the results and will not be a representative for the soil types of the whole area. During construction of the plots, the initial soil cover was removed to a depth of 20cm and replaced with fresh soils of which the studies was to be conducted; care was taken to allow the nature conditions to be in existence that is even after replacing the top soils some time lag was allowed for the soil to fit into the environment. Grasses were allowed to grow on all the plots to create an undisturbed nature of the various soils under consideration while for the disturbed soils, every form of shrubs that must have grown on the various plots are removed and the plot completely cleared of grasses. It is important to note that every effort was made to use the same operations as would normally be used on the farm by the local farmers to have an identical condition of disturbed soil. Several runs of the experiments in the study area were performed which would permit comparison of the measured runoff volumes and to judge on the representative character of the selected plot sites.

Around the edges of the plots, wooden planks were driven into the soil with at least 15 cm of height above ground to stop water flowing from outside into the plot and vice versa. The box was sealed by compacting soil all around it to ensure that only soil and water from the plot could enter into the collecting tank and sampled. A rain gauge was installed near to the plot in areas where there are no obstructions. At the lower end of the plot, a collecting sprout was provided to collect the runoff. The sprout had a gradient of 1% towards the collection tank. The soil around the sprout was backfilled and compacted. The joint between the sprout and the lower side of the plot was cemented to form an apron in order to allow a smooth flow of water from the plot into the collecting tank. The collection tank was made up of plastic tank of 0.25m3capacity which was buried inside the earth at the lower end of the study area.

In determining runoff coefficients for the five types of soils in the study area, three runoff equations were considered based on the available parameters that were determined on the various plots. Table 1 presents the various types of equation considered for the determination of the various runoff coefficients for the types of soils considered during the study period.

Table 1: Various equations considered for the estimate of runoff coefficient

No	Name of equation considered	Equation	Source of equation
1	Rational	$Q = 0.00278CIA$	Eliasson,1996
2	Federal Aviation Administration	$\mathrm{T_c} = \frac{1.8(1.1 - \mathrm{C})\mathrm{L}^{0.5}}{\mathrm{S}^{0.33}}$	Abbott and Refsgarrd, 1996
3	Izzard	$\mathrm{C} = \left(\frac{\mathrm{T_c i}^{0.67}\mathrm{S}^{0.33}}{4\mathrm{iL}^{0.33}}\right) - 0.0007\mathrm{i}$	Fang et. al., 2008

3 Results and Discussion

3.1 Determining runoff coefficient

It is important to note that the physical conditions of a catchment area are not homogenous even at the micro level there are a variety of different slopes, soil types, vegetation covers etc. Though in this study, a standard slope size of 9% was chosen and other physical conditions that exist in the natural environment were replicated as much as possible but each plot had its own runoff response and responded differently to the simulated rainfall events. A total of five runoff plots were analysed for the Gidan Kwano soils of the Federal University of Technology, Minna. There is a large variability in the runoff coefficient determined on the various soils of Gidan Kwano. Table 2 presents the various values of runoff coefficient calculated for the Gidan Kwano soils in comparison with the natural exciting values of slopes ranging between 0 and 6% while Table 3 shows the various values of runoff coefficient calculated for the same study area.

Table 2 here shows that the calculated values of runoff coefficient for slopes of 9%. It was observed that the calculated values using the rational formula ranged between 0.01 and 0.026. The FAA values ranged between -0.162 and -1.321 which is a strong indication for all the soils studied at Gidan Kwano area of the Federal University of Technology Minna no surface runoff was observed while for that of Izzard method, the values ranged between 0.212 and 0.458.Using the existing natural maximum slope value of 6%; it was observed from Table 3 that rational formula had values ranging between 0.010 and 0.026; FAA values ranging between -0.226 and 0.661 while that of Izzard ranged between 0.00 and 0.37. This implies that the undisturbed sandy loam and disturbed clay soil did not experience any form of surface runoff. The Izzard calculated coefficients showed a closer range of values when compared with the existing values of runoff coefficient. The calculated values for Izzard formula ranged between 0.163 and 0.362. In determining these values, it was observed that the results of the rational formula for both the 6 and 9 per cent slope were the same as it did not consider the effect of slopes in the determination of the runoff coefficients. Therefore rational formula is not a better equation for calculating runoff coefficients.

Table 2: Calculated values of Runoff Coefficients (*C*) some selected soil conditions in Gidan Kwano area of Niger state using a slope of 9% and a standard plot length of 22.9 m

No	Type of soil	Soil Condition	Rational	FAA	Izzard
1	Sandy	Undisturbed (Vegetal)	0.014	-1.321	0.452
		Disturbed (Bare)	0.010	-1.252	0.438
2	Sandy Loam	Undisturbed (Vegetal)	0.021	-0.655	0.314
		Disturbed (Bare)	0.017	-0.979	0.381
3	Clay	Undisturbed (Vegetal)	0.026	-0.162	0.212
		Disturbed (Bare)	0.024	-0.345	0.250
4	Loam	Undisturbed (Vegetal)	0.025	-1.321	0.452
		Disturbed (Bare)	0.020	-1.252	0.438
5	Sandy Clay	Undisturbed (Vegetal)	0.023	-0.655	0.314
		Disturbed (Bare)	0.021	-0.979	0.381

Table 3: Calculated *C* values for the various types and condition of soils in Gidan Kwano area of the Federal University of Technology, Minna under existing natural slope.

No	Type of soil	Soil Condition	Rational	FAA	Izzard
1	Sandy	Undisturbed (Vegetal)	0.014	-0.226	0.362
		Disturbed (Bare)	0.010	0.084	0.320
2	Sandy Loam	Undisturbed (Vegetal)	0.021	0.056	0.257
		Disturbed (Bare)	0.017	0.109	0.288
3	Clay	Undisturbed (Vegetal)	0.026	0.428	0.163
		Disturbed (Bare)	0.024	0.331	0.194
4	Loam	Undisturbed (Vegetal)	0.025	0.272	0.303
		Disturbed (Bare)	0.020	0.452	0.269
5	Sandy Clay	Undisturbed (Vegetal)	0.023	0.661	0.181
		Disturbed (Bare)	0.021	0.554	0.228

The difference observed between the values in Tables 2 and 3 is attributed to the difference in the slope gradient of the experimental plots. Despite this, some of the soils showed a good correlation between calculated values and the observed values of the runoff coefficient. Though the FAA determined runoff coefficient showed negative results for all the soils in Table 2 while only the undisturbed sandy soil gave a negative result in Table 3 for soils studied at Gidan Kwano area of Federal University of Technology, Minna which implies that no runoff occurred on the various soils within the study area. Some of the calculated values for FAA in Table 2 showed a close correlation to the existing values of *C*. The izzard calculated values in Table 3 were higher than the already existing values which can be because of the slope gradient difference but when 6% slope gradient was used to determine the runoff coefficient values for the soils considered, they were found to be very close to those values which had already being determined as seen in Table 4.

Considering the runoff coefficient "*C*" values of the maximum slopes for the already existing *C* in comparison with the calculated values of those obtained from Izzard equation, it was observed that the values of Izzard were higher than that the observed or existing values of *C* which can be as a result of the differences in the slope and the condition of the soil of Gidan Kwano area of the Federal University of Technology, Minna. The calculated values of *C* using the rational method or equation showed a slight correlation with the observed data from the existing values of *C* though the existing values of *C* were found to be higher than those of the calculated value. This may be as a result of the antecedent moisture content of the various soils and the slope of the study area.

Yadav *et al*., (2007) observed that using too many properties simultaneously often results in a rejection of all models which was also experienced during the course of this study. Thus the antecedent moisture content of the any soil under consideration for the calculation or determination of *C* is of paramount importance. Although the study area considered here is comparatively small with a slope of 9% but when the natural slope of the study area which ranges between 2% and 6% is applied the various equation, it was observed that the results obtained from the calculation were very close to that of already existing values *C*. Table 4.16 shows the calculated *C* values for the various types and condition of soils in Gidan Kwano area of the Federal University of Technology, Minna.

Table 4: Existing values of *C* for some types of soil condition

	Sandy			Sandy loam			Loam			Clay		
Land Use	0-2%	2-6%	6%	0-2%	2-6%	6%	0-2%	2-6%	6%	0-2%	2-6%	6%
Cultivated Land	0.08	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
	0.14	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Forest Land	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25

4 Conclusion

In the present study, the objective is to develop runoff coefficient for some selected soils in Gidan Kwano area of the Federal University of Technology, Minna, Nigeria and to compare the obtained values with existing values of the coefficient. In a small agricultural and guinea savannah woodland of the study area, the developed empirical runoff coefficients using the developed empirical mathematical model of time of concentration, various values obtained for the various types of soils within the Gidan Kwano area of the Federal University of Technology, Minna can be applied to other soils with similar characteristics in Nigeria as the difference observed between the determined values and the existing values of the runoff coefficients were very close. The difference observed as pointed out could be attributed to the difference in the slope gradient of the study area. It can therefore be concluded that if the slope of 6% is maintained the values of runoff coefficient will be the same as those that are in existence.

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