DEVELOPMENT OF AN EMPIRICAL HYDROLOGIC MODEL TO DETERMINE MANNING AND RUNOFF COEFFICIENT FOR SOME SELECTED SOILS OF THE PERMANENT SITE OF FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

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Abstract
The determination of the volume and rate of movement of surface water within a watershed are the fundamental steps upon which the design of reservoirs, channel improvement, erosion control structures and servers as well as agricultural, highway and various drainage systems are based. The concept of integrated watershed runoff coefficient has emerged as a new understanding for the interactions between the surface and subsurface pathways of water. A runoff plot was set up to measure surface runoff for the type of soil under controlled conditions. The plot was established directly in the project area with a slope of 9% and length of 22.9 m. Several runs of the experiment were conducted on the plot to help determine the type of parameters (amount of surface runoff, time of concentration, slope, and rainfall intensity) that will be considered for the development of the model. The model developed for this study is $T_c = 0.938L^{0.878}n^{0.324}\theta^{-0.222}S^{-0.049}i^{-0.075}$. *This was compared with already existing models and it proved to be a better model to determine Manning-Nigeria coefficient.*

Keywords: Hydrologic model, Manning Coefficient, Nigeria, Runoff coefficients Soils

Introduction

As a watershed begins to accept precipitation, surface vegetation and depressions intercept and retain a portion of that precipitation. Interception, depression storage and soil moisture each contribute to groundwater accretion, which constitutes the basin recharge (Nathanail and Bardos, 2004). Precipitation that does not contribute to basin recharge is direct runoff (Motha and Wigham, 1995). Direct runoff consists of surface runoff (overland flow) and subsurface runoff (interflow), which flows into surface streams. The basin recharge rate is at its maximum at the beginning of a storm, and decreases as the storm progresses (Morita and Yen, 2002).

Basically, a method is needed whereby, for known or assumed conditions within a watershed, the runoff hydrograph resulting from any real or hypothetical storm can be predicted with a high degree of reliability. Such a method must be sufficiently general to allow the determination of the change in system response that would result from proposed water management projects within the watershed. Only with this type of analysis can such projects be designed on a rational basis to produce optimum conditions for a minimum cost.

The concept of integrated watershed runoff coefficient has emerged as a new understanding for the interactions between the surface and subsurface pathways of water. This defines the bidirectional linkage that implies the main rationale for the unity of the two systems. In this regard, surface flow processes such as channel and overland flow are integrated to subsurface flow process in the unsaturated and saturated ground water flow zones via the dynamic interactions at the ground surface and channel beds. Only with this kind of approach can one determine a standard coefficient for some major soils in a watershed.

The objective of this study was to develop an empirical model that could be used in any part of Nigeria to determine the Manningcoefficient for any particular soil in any given area where construction works are to be carried out.

Methodology

Study area

The permanent site of the Federal University of Technology, Minna is known to have a total land mass of eighteen thousand, nine hundred hectares (18,900 ha) located along kilometre 10, Minna–Bida Road, South–East of Minna, in Bosso Local Government Area of Niger State, Nigeria. It is a horse–shoe shaped stretch of land, lying approximately on longitude of 06^{0} 28′ E and latitude of 09^{0} 35′ N. The entire site is drained by Rivers Gwakodna, Weminate, Grambuku, Legbedna, Tofa and their tributaries. They are all seasonal rivers and the most prominent among them is River Dagga. The most prominent of the features are River Dagga, Garatu Hill and Dan Zaria Dam (Musa, 2003).

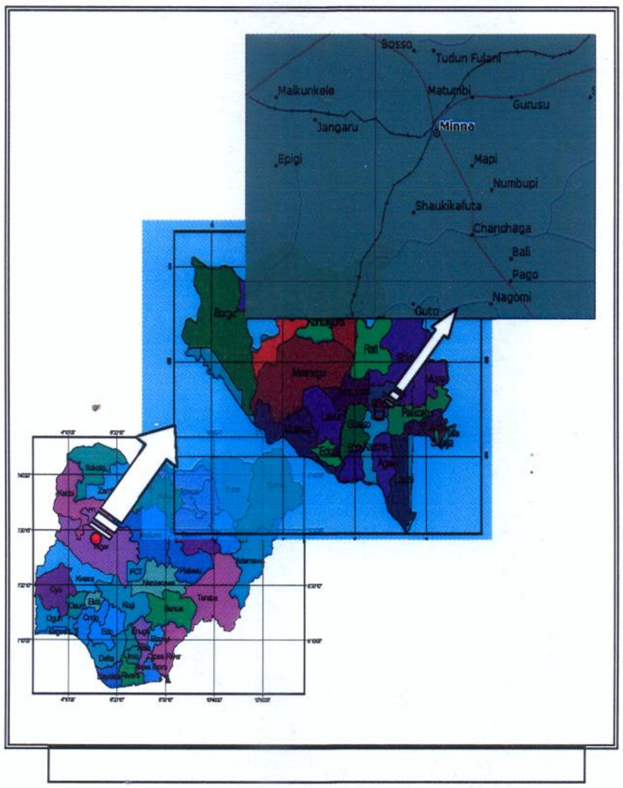

Figure 1: Map of Minna extracted from the maps of Niger State and Nigeria

Runoff plots

A runoff plot was set up to measure surface runoff for the type of soil under controlled conditions. The plot was established directly in the project area with a slope of 9%. The required type of soil

was excavated at 20cm depth from another location and was used to replace the current type of soil existing within the constructed runoff plot. The soil was then ramped to the initial bulk density measured in the field.
Care was taken to avoid study areas with farmlands, rills, soil cracks, or gullies crossing the plot as these could affect the results to be obtained and might not be representativeof the soil type within the area. The gradient/slope from the starting point was 9% and the end point it was 0% which was free of local depressions (this was constructed for each of the runoff plots). During plot construction, the top soil was removed to a depth of 20cm and replaced with fresh soil for which the studies was to be conducted; care was taken to allow the natural conditions to be restored 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 soil under consideration. Several runs of the experiments were conducted on the plot to help determine the type of parameters to be considered for the development of the model.

The following parameters were considered for the development of the model: moisture content, length of the plot, slope of the plot, rainfall intensity, and the travel time (time of concentration) of runoff from the starting point of the field to the end point of the same.

Results and Discussion
Based on the numerical model developed by Papadakis and Kazan (1986) from the Navier-Stokes equations, the empirical mathematical model for the determination of the time of concentration was developed for the simulation of sheet flow over the land surface. The overall slope of the land was fixed at 9% with a standard length of 22.9m to mimic the situation explored in the problem statement. The simulated land surface also incorporated micro topography, which allowed various simulations of surface roughness. This model,that is the Papadakis and Kazan (1986) from the Navier-Stokes equations had the following variables of length of the watershed, surface roughness (usually Manning's n), slope of the watershed, and rainfall intensity.

The model is expressed as:

$$T_c = kL^a n^b S^{-y} i^{-z} \qquad \text{Equation 1}$$

where T_c is the time of concentration, L is the watershed length, n is Manning's n, S is the watershed slope, and i is the rainfall intensity. k is a constant and a, b, y, z are exponents. This equation exhibits a linear correlation of the logarithms of the variables involved. It was observed that the antecedent soil moisture had a strong influence on the surface runoff travel time for the season considered. Using the above model, the empirical mathematical method and Crammer's rule were employed to determine the various exponents for the mathematical model for some selected soils in Gidan Kwano area of Minna, Niger State. In developing this equation, the antecedent moisture content for these soils was put into consideration. The model developed for this study is stated below as:

$$T_c = 0.935L^{0.878} n^{0.324} \theta^{-0.222} S^{-0.049} i^{-0.075} \qquad \text{Equation 2}$$

where
Tc= time of concentration in minutes,
L = watershed length of the study area in meters,
n = Manning's n for some selected soils in Gidan Kwano,
θ = antecedent soil moisture in percent,
S = watershed slope, and
i = rainfall intensity in mm/hr.

From equation 3, making n our subject of formula we have that

$$n^{0.324} = \frac{T_c}{0.938L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075}}$$ Equation 3

and on taking the log of both sides, *n* became

$$Logn = \frac{LogT_c - 0.938Log\,(L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075})}{0.324}$$ Equation 4

Equation 4 above was used to determine the Manning coefficient for some selected soils (sandy, sandy loam, clay loam, sandy clay and loamy), considered in this study. It was observed that *S* variable had the least influence on the Manning coefficient for those soils considered in the Gidan Kwano area as *S* has the least exponent figure among all variables. Table1presents a summary of the calculated exponents for each of the variables of the model developed.

Table 1: Calculated exponential values of the developed model

Exponents of Parameters	Coefficients
k (constant)	0.938
x (exponent of θ)	-0.222
b (exponent of *n*)	0.324
y (exponent of *S*)	-0.049
z (exponent of *i*)	-0.074

Using the various calculated values of time of concentration for the various equations which were considered not to have to use the already determined values of *n*; it was observed from Table 2 that the time lag equation gave a better result of *n* values for the Gidan Kwano soils of the Federal University of Technology, Minna. It was also observed that the best time of concentration was that determined using the time lag equation which initially could be considered as being too short for water to travel from the most remote area of the plot to the point of collection bearing in mind that the rainfall simulator provided water in all areas of the plot almost at the same time are at a steady rate of flow. From the same table, it was also observed that undisturbed sandy loam and disturbed clay soils had *n* values of 0.00 respectively which implies that no surface runoff occurred and Manning's values may be adopted under these two soil conditions but for the other types and various conditions of soils the values developed can be adopted for soils of similar conditions within Nigeria. The *n* values obtained ranged between 0.00 (for undisturbed sandy loam and disturbed clay soils) and 0.37 for undisturbed sandy soil. When the values of the research work were compared with the figures obtained by Manning, they were very much similar though he did not work on specified soils as presented in this research.

Table 2: Manning's *n* values using various calculated values of time of concentration for the developed mathematical model

S/no	Type of soil	Condition of soil	SCS Tc	FAA Tc	Time Lag Tc
		Undisturbed	3.70	8.87	0.37
1	Sandy	Disturbed	3.48	8.73	0.33
		Undisturbed	1.98	8.41	0.03
2	Sandy Loam	Disturbed	2.69	8.26	0.14
		Undisturbed	0.68	7.64	0.00
3	Clay	Disturbed	1.11	8.17	0.00
		Undisturbed	1.03	7.91	0.25
4	Loam	Disturbed	1.42	7.66	0.22
		Undisturbed	1.82	8.09	0.01
5	Sandy Clay	Disturbed	2.70	8.41	0.15

Where SCS is the Soil Conservation Service, FAA is the Federal Aviation Administration and T_c is the time of concentration.

Conclusion

Itcan be concluded that the values of *n* obtained from the developed model to calculate time of concentration showed that SCS and FAA equations cannot be used to compare with the already existing values of Manning coefficient as the determined ones were seen to be higher. The values of time lag equation values were found to be very close to that of the existing values of Manning coefficient. Thus, this should be used for the design of some basic agricultural water structures to test the durability of the structures over time.

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