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

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ABSTRACT

Collapse and failure in infrastructures in Nigeria has been a concern to the hydrologist community in Nigeria. Hence the need to determine Manning coefficient for some selected types of soil. Models that describe watershed hydrology are classified according to several criteria. One of the most significant of these classifications is based on the spatial variability of the parameters that define the flow processes Hydrologic empirical models are developed with little or no consideration to the underlying physical theory and attempt to explain the natural behavior by using simple input-output relationships. With the soil types and particle sizes of the study area determined, samples were collected from each area and placed within the experimental plots and identified. Five 22.9 m by 2 m standard runoff plots with a standard slope size of 9% were prepared and soils to be studied were collected and placed in the various runoff plots to replace the existing soils in the plots. Times of concentration for the five plots were determined using five empirical equations. The results shows that the soil samples of the study area are sandy, sandy loam, clay loam, sandy clay and loamy soils. Time of concentration ranged between 14 and 27 minutes, 49.01 and 52.14 minutes and 11.17 and 6.18 minutes for SCS, FAA and time lag equations respectively. The n values obtained ranged between 0.68 to 3.70, 7.64 to 8.87 and 0.00 to 0.37 for SCS, FAA and time lag values of time of concentration. It can be concluded that the calculated Manning and runoff coefficients for the study area which is higher than the existing one should be used in the design calculation of structures.

KEYWORDS: Manning Coefficient, Time of concentration, travel time, lag time, runoff.

INTRODUCTION

The dynamics in soil types in Nigeria are fast changing in the face of urban sprawl and urban consolidation. Development in Nigeria has observed swamp lands into various forms of irrigation farms where concretes of waterway structures are developed to convey water to various farm plots. Increased social awareness of the need to protect and manage our water resources has also had a significant impact in highly urbanized catchments. Residents are encouraged to employ best management practices (e.g., rain gardens, rainwater tanks etc.). These developments range in scale, but they share a common attribute; they increase the heterogeneity and non-linearity of the urban landscape. As a result, the path for a drop of rainfall has changed and is inherently more complex and difficult to predict.

The determination of the volume and rate of movement of surface water within a watershed is the fundamental step upon which the design of reservoirs, channel improvement, erosion control structures, and servers as well as agricultural, highway and various drainage systems is based. Quantitatively describing the rate and path of movement of a rain droplet after it strikes the ground surface is essential for the rational development and efficient utilization of our nation's water resources.

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 change in system response that will result from proposed water management projects within a 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 primary objective of this study is to develop manning 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.

Models that describe watershed hydrology are classified according to several criteria. One of the most significant of these classifications is based on the spatial variability of the parameters that define the flow processes (Abbott and Refsgaard, 1996). In this regard, a distributed parameter model takes into account the spatial variability in all parameters of concern, whereas a lumped parameter model assumes the watershed to be single unit with variables and parameters representing average values for the entire catchment. From this perspective, a lumped parameter model downscales and simplifies a complex system to a single unit entity.

In differentiating watershed and urban catchment hydrologic modeling, it is important to consider a number of the key scale issues identified by Blöschl and Sivapalan (1995). In their review, Blöschl and Sivapalan (1995) focused primarily on watershed or catchment hydrology. However, many of the issues they discuss are prevalent in hydrological modeling of urban catchments. In urban catchments, only subsets of these hydrological processes are generally considered, namely; precipitation, subsurface storm flow, infiltration excess overland flow, saturation excess overland flow and channel flow while watersheds can have time scales ranging from minutes to years, urban catchments typically have time scales in the range of minutes to hours Cantone (2010). He further stated that given these differences in the time and spatial scales it is recognizable that urban catchments are effectively a portion of larger natural watersheds; the key physical distinction being in land surface characteristics. Urban catchments tend to be highly impervious, with the predominant land use being residential, commercial and industrial. In contrast, natural watersheds tend to be highly pervious, with the land use dominated by pasture, crop land, and other agricultural land cover. As a result of the greater portion of impervious area, the travel times in urban catchments are often significantly less than watersheds.

On the opposite extreme, empirical models are developed with little or no consideration to the underlying physical theory and attempt to explain the natural behaviour by using simple input-output relationships. In this regard, this type of a model is generally called a “black box” model about which the modeler has often little or no physical understanding of its processes. It serves as a simple mechanism that converts the input information to some sort of an output response without any consideration of the internal characteristics of the process (Abbott and Refsgaard, 1996).

The empirical hydrological methods are amongst the best known black box models. Unit hydrograph theory and Soil Conservation Service (SCS) curve number methods are examples of this type of model. The statistically-based methods include many models developed using regression and correlation analysis of the available data. These methods are also called the transfer function models that convert an input time series to some output time series. An example of this type of black box model is the Antecedent Precipitation Index (API) model that correlates rainfall volume and duration, past days of rainfall and season of year to runoff. Finally, a new group of black box models called the hydro-informatics-based methods are developed in parallel with the recent advances in information technology such as artificial neural networks and genetic algorithms. It is, however, important to note that, regardless of the level of advancement achieved with an empirical model; it will always be one step behind the physics-based models as the latter provides a thorough and more correct description of the hydrological processes in a watershed (Singh and Woolhiser, 2002).

Data requirements of watershed models are one of the major issues that the hydrologic modeller has to focus on. Such models are based on spatial variability of parameters over the watershed area, the input data are expected to be compatible and satisfy the needs of each model component.

The term runoff is a descriptive term which is used to denote that part of the hydrologic cycle which falls between the phase of precipitation and its subsequent discharge in the stream channels or direct return to the atmosphere through the process of evaporation and evapo-transpiration (Raghunath, 2006). Before runoff in a watershed can actually take place there must be a dry period and at the end of the dry period, there begins an intense and isolated storm. During this stage, all surface and channel storages get depleted, except in reservoirs, lakes, and ponds, from the previous storms. Under this condition, the source of stream flow is only the ground water flow which decreases with time. After the beginning of rainfall and before saturation of interception is the depression storage. Here every precipitation falls directly on the land surface or on stream surface which provides an immediate increment of stream flow (Strum, 2001).

Most of the rain water, reaching the ground are either retained on the surface or passed into the soil through the process of infiltration (Raghunath, 2006). Once the rain water is infiltrated into the soil it will start to replace the lost water within the soil environment without contributing to the ground water. During this process overland flow only takes place only from those parts of the watershed that are impervious in nature such as road e.t.c. which over the soil surface it does not occur as the rain water is consumed by several losses such as depression storage and infiltration loss. As the rainy season/period approaches the end of an isolated intense storm, a long period of continuous intense storm, all losses such as the interception by vegetative foliage and depression storages on land surface are satisfied and infiltration rate is reduced to the barest minimum level; thus becoming one of the major source of surface flow for the entire watershed

(Merz *et al*., 2006). During this period, the sub-surface flow has started and towards the stream flow. In this stage, rainfall causes the overland flow, base flow, and development of channel storage.

The Manning formula, known also as the Gauckler–Manning formula, or Gauckler–Manning–Strickler formula in Europe, is an empirical formula for open channel flow, or free-surface flow driven by gravity. The Gauckler–Manning formula states:

$$V = \frac{k}{n} R_h^{2/3} S^{1/2} \tag{1}$$

where V is the cross-sectional average velocity (ft/s, m/s), k is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units n is the Gauckler–Manning coefficient (independent of units), R_h = is the hydraulic radius (ft, m) and S is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) ($S = h_f/L$).

The discharge formula, $Q = A\ V$, can be used to manipulate Gauckler–Manning's equation by substitution for V. Solving for Q then allows an estimate of the volumetric flow rate (discharge) without knowing the limiting or actual flow velocity. The Gauckler–Manning formula is used to estimate flow in open channel situations where it is not practical to construct a weir or flume to measure flow with greater accuracy. The friction coefficients across weirs and orifices are less subjective than n along a natural (earthen, stone or vegetated) channel reach. Cross sectional area, as well as n', will likely vary along a natural channel. Accordingly, more error is expected in predicting flow by assuming a Manning's n, than by measuring flow across a constructed weirs, flumes, or orifices.

The formula can be obtained by use of dimensional analysis. Recently this formula was derived theoretically using the phenomenological theory of turbulence (Vanderkwaak and Loague, 2001).

The primary objective of this study is to develop manning 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.

MATERIALS AND METHOD

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 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).

Site setup

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% and plot size of 2m by 22.9m. 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. 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 plots were categorized into the disturbed and undisturbed soils on the same site for the various types of soils under consideration within the Federal University of Technology, Minna Niger State. Each of the sites had both the disturbed and undisturbed condition of soil. The bear/disturbed soils were carried out by treating (hoeing) the various plots.

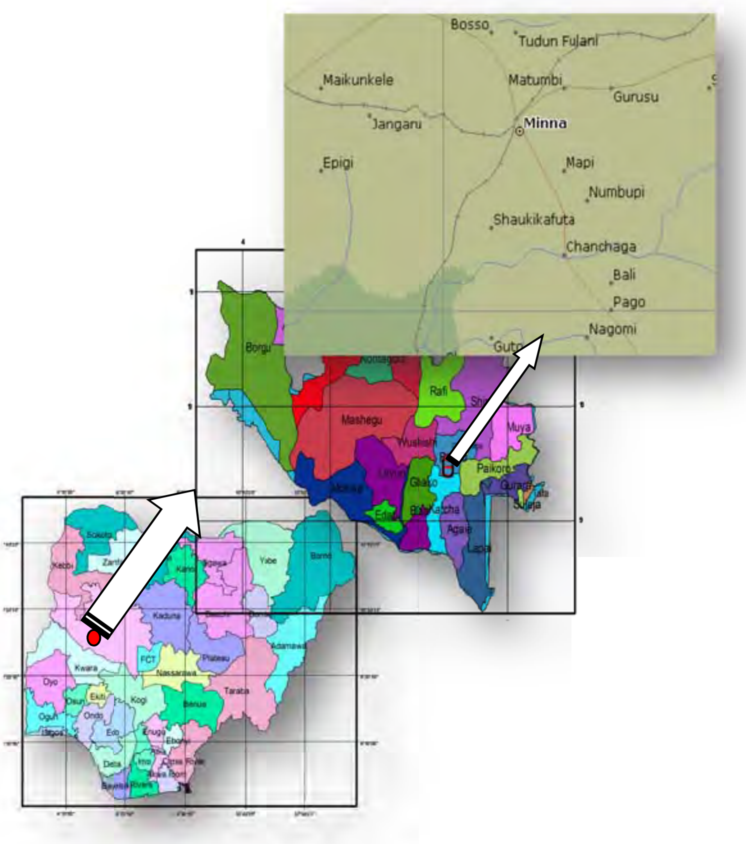

Figure 1: Map of Minna extracted from the map of Niger State and that of Nigeria

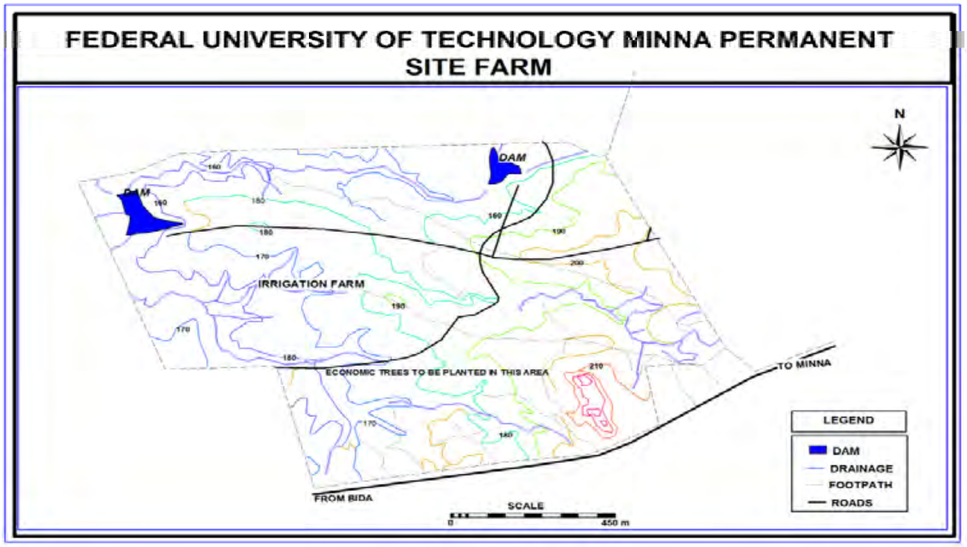

Figure 2: Contour map of the Irrigation farm site of the Federal University of Technology, Minna

Determination of Time of Concentration

There are many ways to estimate T_c; formulas exist for predictions of overland and channel flow. In this study, time of concentration (T_c) is estimated for from a standard plot size of 2m by 22.9m using five empirical equations: Kirpich (1940), Bransbey Williams (1922), Federal Aviation Administration (FAA, 1970), Soil Conservation Service (SCS, 1986), and the time lag formula developed by the National Resource Conservation Service (NRCS) methods. These equations were selected based on the availability of the various watershed parameters in duplicating local hydrologic estimates. Some of the parameters considered include watershed drainage area, channel length, watershed or channel slope, and watershed shape parameters. These parameters can be difficult and time consuming to estimate. Table 1 shows the System International (SI) units of the various equations considered.

Table 1: Various equations considered for the estimate of time of concentration

S/No	Method/Equations	Equation in SI units
1	Kirpich	$T_c = 0.0078\frac{L^{0.77}}{S^{0.385}}$
2	Bransby Williams	$T_c = 21.3\ \frac{L}{5280A^{0.1}S^{0.2}}$
3	Soil Conservation Service (SCS)	$T_c = 0.00526L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7} S^{-0.5}$
4	FAA	$T_c = \frac{1.8(1.1-C)L^{0.5}}{S^{0.33}}$
5	NRCS Time Lag	$T_L = \frac{2.587L^{0.8}\left(\frac{1000}{CN-9}\right)^{0.7}}{S^{0.5}}$ but $T_c = \frac{T_L}{0.6}$

In Table 1, Q is the rate of discharge, C is the dimensionless runoff coefficient, I or i is the rainfall intensity, A is the area of watershed, L is the length of watershed, S is the slope of watershed and Tc is the time of concentration.

RESULTS AND DISCUSSION

Time of concentration

The calculated time of concentration for the various types soils under the vegetated (undisturbed) and bear (disturbed) conditions using Kirpich (1940), Bransbey Williams (1922), Federal Aviation Administration (FAA, 1970), Soil Conservation Service (SCS, 1986), and the time lag formula developed by the National Resource Conservation Service (NRCS) methods are presented in Table 2.

Table 2: Calculated time of concentration for various condition of soil using various equations

S/no	Type of soil	Soil Condition	Kirpich Equation (mins)	Bransbey Williams Equation (mins)	SCS Equation (mins)	FAA Equation (mins)	Time Lag Equation (mins)
1	Sandy	Undisturbed	50	43.06	27	52.14	11.09
		Disturbed	50	43.06	26	51.33	10.77
2	Sandy Loam	Undisturbed	50	43.06	20	51.14	8.04
		Disturbed	50	43.06	23	50.12	9.52
3	Clay	Undisturbed	50	43.06	14	49.01	5.78
		Disturbed	50	43.06	16	51.03	6.62
4	Loam	Undisturbed	50	43.06	16	51.03	11.09
		Disturbed	50	43.06	18	49.01	10.77
5	Sandy Clay	Undisturbed	50	43.06	20	51.34	8.04
		Disturbed	50	43.06	23	50.33	9.52

It was observed from Table 2 that Kirpich and Bransbey Williams' equations had fixed values of 50 and 43.06 minutes respectively which is not a good representation of the various types of soils existing within the study area. The Soil Conservation Service (SCS) equation calculated the time of concentration to range between 14 and 27 minutes which had as one of its parameters the curve number. The curve number is the parameter used by the equation to estimate the potential maximum retention of rainfall which will result in direct runoff. The curve number depends mainly on the type of soil, land use and antecedent moisture conditions. Because of the tightly packed nature of clay, it was observed to have the shortest time of concentration of 14 minutes while sandy soil had the longest time of concentration of 27 minutes. Though, Soil Conservation Service (SCS) equation values were not used for the determination of the *n* value of some of the selected soils but it served as a guide to the equation that will best describe the time of concentration of the various soils. On examination of the Federal Aviation Administration

(FAA) equation, it was observed that the time of concentration ranged between 49.01 and 52.14 minutes. The FAA equation gave a more precise time of concentration because of the various parameters present within the equation, the values of *C* (dimensionless runoff coefficient) used here shows a precise relationship between rainfall and runoff of the study area. It was further observed that the time of concentration for the undisturbed soil was 52.14 minutes while the disturbed soil was 51.33 minutes. This shows a difference of 1minute and 21 seconds which shows that some quantity of water flowing on the surface of the plot had infiltrated and necessary depressions filled. Though, the difference in timing was not much between the undisturbed and the disturbed sandy soil because very limited depression excited along the slope but it took a long time before the time of concentration was reached. This trend was also observed in the other types of soil for almost all the equations except for those that had fixed values of time of concentration for the various soils. When the time lag equation was used, it was observed that the time of concentration ranged between 6.18 and 11.17 minutes. Considering the length of the experimental plots, it was observed that the calculated time of concentration for each of the plot was too short.

Using the various calculated values of time of concentration for the various equations as presented in Table 2 above, the calculated figures for SCS, FAA and time lag equations were used to calculate the *n* values for the various types and condition of soils using the developed model of $T_c = 0.935L^{0.878}n^{0.324}\theta^{-0.222}S^{0.049}i^{-0.075}$ where *L* is the length of the watershed, *n* is the manning coefficient, θ is the antecedent moisture content, *S* is the slope of watershed and *i* is the rainfall intensity. Table 3 below presents the *n* values using various calculated values of time of concentration for the developed mathematical model.

Table 3: *n* values using various calculated values of time of concentration for the developed mathematical model

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

It was observed from Table 3 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.

CONCLUSION

The Natural Resources Conservation Services (NRSC) also called the time lag equation best calculates the time of concentration for the study area as it covers the entire are of the study plots thus a short time is spent for water to travel from the most remote area to the point of collection depending on the nature and condition of the study area. The calculated time of concentration for Time lag equation should be used as one of the parameters to develop the Manning coefficient for some soils of Gidan Kwano of Minna, Niger State.

The developed Manning coefficients and relationships 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. The calculated values of Manning coefficients can be adopted as a design parameter for various types of construction works within the irrigation farm site of the Federal University of Technology, Minna, Nigeria. Finally, it has been shown that this model provides improved understanding of the hydrologic and hydraulic processes that are most important to the local farmers and structural engineers in Nigeria.

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