THE INFLUENCE OF SLOPE ON SPATIAL VARIABILITY OF INFILTRATION CAPACITY IN OBUDU LOCAL GOVERNMENT AREA OF CROSS RIVER STATE, NIGERIA

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Abstract

Infiltration as a term describes the flow of water through the soil surface. It also describes the process by which water soaks and is absorbed by the soil. Slopes of varying steepness and aspect will get different amount of rainfall-runoff which may influence the amount of infiltration. The study is aimed at examining the influence of slope on the variability of infiltration capacity in Obudu Local Government Area of Cross River State, Nigeria. The slope was dichotomized into three segments based on the geomorphological zonation. Four transects were marked out in each of the slope segment. Two soil samples were randomly collected at the upper, middle and bottom slopes and were taken to the laboratory for the analysis of moisture content. The steel cylinder were firmly driven into the soil to a depth of 5cm with the aid of a hand hammer. The wooden plates were then used to ascertain if the steel cylinders are balanced enough. The wooden plates were then placed on the steel cylinder and invert the already filled bottle on it through a hole on wooden plate. Reading starts immediately the bottles have been inverted over the steel cylinder. The data from each test were expressed in the form of the Talsma-Parlange equation which is also similar to the Philip's two equation in terms of sorptivity, S, and the saturated hydraulic conductivity, ks. The results revealed that there was no obvious variation in the values of infiltration on the upper, middle and bottom slope segments. The ANOVA results further established the difference between the values of infiltration, diffusion and transmission contents and the mean of infiltration capacity on the upper, middle and lower slope segments along the toposequence. The result revealed an insignificant variation in the values on the various segment of the slope. The study has established how much of an influence slope has on water infiltration as a geomorphic process.

Keywords: Slope, Infiltration Capacity, Spatial Variability and Obudu

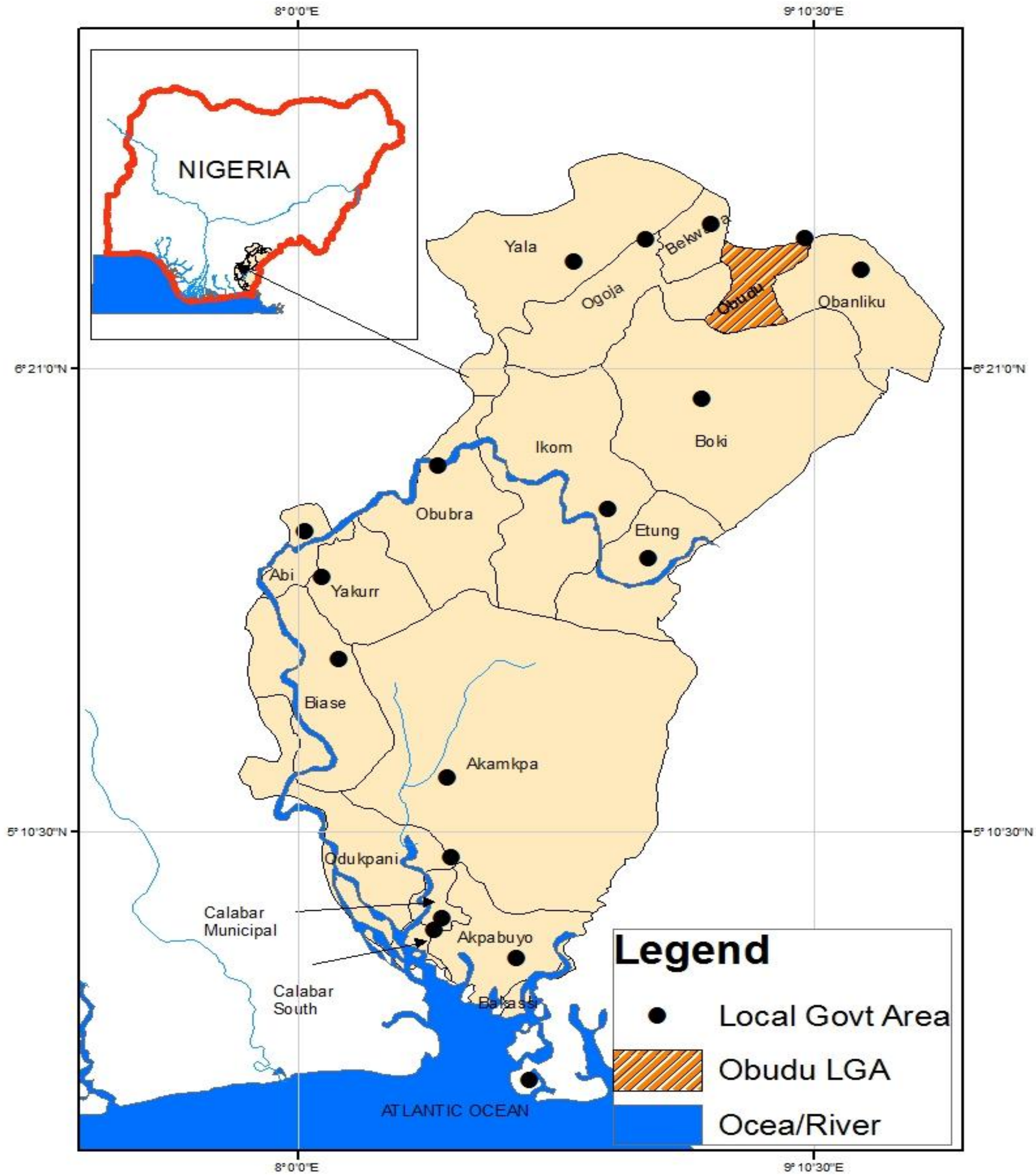
1. Introduction

Infiltration as a term describes the flow of water through a soil surface. The term was first used by Horton (1933) to describe the entry of water into the soil. It also describes the process by which water soaks into the soil and is absorbed by the soil (Ayoade, 1988; Eze & Abua, 2002).

Infiltration as a process is measured in the field as the depth of water entering the soil at a given time. The pioneering study of Musgrove and Holton (1964) shows that infiltration process has three main components, namely surface entry of water, movement through the soil (transmission) and reduction of the soil's storage capacity. Infiltration is distinguished from percolation, which describe the free download flow of water towards the water table under the force of gravity and hydrostatic pressure.

From the above, it is obvious that for infiltration to take place, water must enter the soil surface and be transmitted through the soil and then stored within the soil. For example, rainwater when it enters the soil would continue so long as the water is being transmitted downloads through the soil profile. The transmission capacity of the soil is related to the permeability, which varies according to the soil texture and structure (Eze & Abua, 2002; Arnell, 1999). Every soil therefore, has an infiltration capacity which is the maximum rate at which rainfall can be absorbed by the soil in a given condition (Ayoade, 1988; Eze & Abua, 2003). The infiltration capacity is determined by porosity, thickness of the soil profile and antecedent moisture conditions. Furthermore, the infiltration rate is the amount of water that passes through the soil in unit time. The amount is expressed in unit of depth such as millimeters while the actual infiltration capacity of the soils is equivalent to the infiltration rate (Eze & Abua, 2002).

Infiltration influences the pattern of runoff, soil moisture regime and evapotranspiration. Infact, infiltration is an important factor as it determines what happens to rainfall within catchments. Infiltration assumed to be a straight-downward vertical unsaturated flow into the soil is highly variable depending, in the first approximation, on the degree of anisotropy, the slope and its changes (Eze and Abua, 2002; Taffa, 1990b; Horton, 1939; Taffa, 1991a). In a sloppy soil, the combined force of gravity and pressure gradient will usually deviate away from the normal, in a downhill direction under these conditions, one would always expect, in addition to the flow component normal to the soil layer, a downhill, lateral, flow component parallel to the soil layer (Waten, et al., 1986; Blaikie, 1985; Carstein, 1982; Ackers, 1993).



Clearly, slopes of varying steepness and aspect will get different amount of rainfall-runoff which may influence the amount of infiltration. Rainfall, runoff and soil loss are important processes in slope formation. They are processes that work hand in hand as being energized and determined by rainstorm event. In the light

Fig. 1: Map of Cross River State: The Study Area

of this, rainfall amount, intensity and duration are parameters that are also needed to be studied if both predictions, and post dictions have to be made as regards rainfall, runoff, infiltration and soil loss interrelationship along a toposequence (Taffa, 1996; Yoshino, 1990; Creutin et al., 1982).

Field evaluation has however shown that researches have work extensively on slope on infiltration rate on different land uses as there are death of information on the rate of infiltration along a toposequence in Obudu, hence the thrust of the study which seeks to examine hydraulic analysis to characterized the influence of slope factor on the spatial variability along a toposequence. The aim of this study is to examine the influence of slope on the variability of infiltration capacity in Obudu Local Government Area of Northern Cross River State, south-South-Nigeria.

2. Materials and Methods

Study Area

Obudu Local Government Area is located in the northern part of Cross River State, Nigeria. It lies between longitude $8^0 55^I$ and $9^0 15^I$ east and latitude $6^0 22^I$ and $6^0 40^I$ north. It is bounded by Benue state in the north, in the south by Boki Local Government Area, in the east and west by Obanliku and Bekwarra Local Government Areas respectively. It is a mountainous area north of the Cross River National Park with an altitude of about 5,000ft. The area falls within the tropical humid climate. Temperature is fairly high all year round with pronounced seasonality (Abua & Ajake, 2015; Abua & Digha, 2015) (Fig. 1).

Materials

The toposequence was dichotomized into three segments based on the geomorphological zonation. In each of the three categorization of the slopes, four transects were marked out in each of the slope segment. Along each of these transects, at least two soil samples were randomly collected at the upper, lower and bottom slope segments as this was due to the variability in the areal extent of the slope surfaces because the middle slope was not as long as the upper and bottom slope segments. The soil samples collected were taken to the laboratory for soil moisture content determination.

The equipments used in the study include infiltrometer cylinder, made up of one steel cylinder. 10cm in diameter, 15cm long, 5mm thick at the top and feeder bottle assemblage consisting of one straight-sided glass tube bottle with a size of 5 litres and with appropriate sizes of rubber bungs to be able to produce an air-tight effect for the bottles, and 2 glass tubes of the same size, preferably between 2 and 3mm and approximately 15cm long. Supporting frame and other which include one wooden plate (15cm square and 1.5cm thick) made of tough tropical hardwood with a hole of diameter 7.5cm bored at the centre to fit the neck of the feeder bottle. A hand hammer and one 5 litre funnel for feeder water into the feeder bottle and an auger for taking soil samples to indicate the depth of a soil horizons use for the determination of moisture content (Akintola, 1974).

Fieldwork

The toposequence was dichotomized into three segments based on the geomorphological zonation (Upper, middle and bottom slopes). In each of the three categorization of the slope, four transects were at least marked out in each of the slope segment. Along each transect, at least two soil samples were collected at the upper and bottom slope segments and one soil sample at the middle slope segments. This was due to the variability in the areal extent of the slope surfaces as the middle slope was not as long as both the upper and bottom slope segments. The soil samples collected were taken to the laboratory for soil moisture content determination.

The steel cylinders were firmly driven into the soil to a depth of 5cm with the aid of a hand hammer without removing any vegetation unless such would pose a hindrance. Thereafter, the little plumb was used to ascertain if the steel cylinders are balanced enough. The wooden plates were then placed on the steel cylinder and invert the already filled bottle on it through the hole on wooden plate. Reading starts immediately the bottles have been inverted over the steel cylinder. Reading of the meniscus of the water level is done against the glued scale on the outside of the bottle graduated in centimeters.

In any case, if it happens that the tube through which water gets out is higher than the water in the bottle then the bottle had to be refilled immediately hence, there has to be some stand-by water in the containers for refilling whenever, the water in the bottle is lower than the water tube inside. Readings of the graduated bottles was done or made at intervals of 5 minutes until equilibrium was attained after 40-60 minutes.

Because the soils in the study area are excessively stony and very dry (coarse) then it is often very difficult to use soil tubes or coring devices. The screw auger was employed in this study for soil sampling. Plastic bags were used in the collection of soil samples from the field to minimize the problem of moisture loss in the process of transferring the samples to the laboratory for analysis.

Determination of Infiltration Parameters

Philip (1957), Talsma (1969) and Braster (1973) suggested that the value of Ks in the equation –

$$I = St^{1/2} + {}^{1/3}Kst + {}^{1}/_{9}\,\frac{K^2S}{S}\;({}^{3}/_{2} \quad - \quad - \quad - \quad - \quad \text{equ. 1)}$$

lie between $^2/_3$Ks and $^1/_3$ KS, but usually closer to $^1/_3$KS, where Ks is the saturated and hydraulic conductivity. In previous works (e.g. Talsma, 1969; Talsma & Parlarge, 1972) also suggested that the 'S' parameter which is sorptivity, can be evaluated directly. In this study, these parameters were calculated from infiltration data, sorptivity, 'S' was calculated as the slope of an infiltration (I) versus time ($t^{1/2}$) plot which should be linear. With these parameters the graph of the different curves of the slope were plotted.

3. Laboratory Analysis

The gravimetric method was adopted for the determination of soil moisture content (Reynolds, 1970). The samples of soil were transported to the laboratory, weighed, dried at 105% in an oven until a constant weight was achieved after 24 hours and reweighed. The loss in weight was then used to calculate the moisture content and expressed as a percentage of the oven dry weight of soil. The moisture content was calculated using the formula thus:

$$Mc = \frac{Ww - Wd}{Wd} \times 100 \quad - \quad - \quad - \quad - \quad \text{(equ. 2)}$$

Where Mc = Moisture content in % by weight

Ww = Wet weight of the sample including the weight of soil grains plus water.

Wd = Dry weight of samples, this includes the soil grains plus some hygroscopic water.

Method of Data Analysis

The statistical tool employed to analyze the data was the Analysis of Variance (ANOVA). The ANOVA was used to examine whether there is any significant variation in infiltration values along the toposequence (upper, middle and bottom slopes).

4. Results and Discussion

From the results of the analysis the mean transmission constant values for the upper, middle and bottom slopes are 0.86, 0.97 and 0.66 respectively while the diffusion constant of the upper, middle and bottom slopes, revealed the means of 2,52, 2,59 and 1,81 respectively was significant at the 0.05 level inferring that there is no significant variation in the infiltration capacities of the upper, middle and lower slopes of the catena (Tables 1 and 2).

Table 1: Results of Transmission constant along a toposequence in the study Area.

Cromophological Zones	**Upper slope**	**Middle Slope**	**Lower Slope**
Diffusion Constant	2.515	2.586	1.813
Standard Deviation	2.142	1.921	1.201
Mean Transmission Constant	0.864	0.966	0.662
Standard Deviation	0.812	0.571	0.401
Mean Infiltration Capacity	3.564	3.538	2.509
Standard Deviation	2.904	2.393	1.473

The transmission constant is a parameter in the infiltration equation which approximates the constant rate of infiltration at saturation. These values of transmission constant above can be explained by the fact that the transmission constant is governed by the size and frequency of the spaces within the soil. A glance at the table of transmission constant, also show an in disparity or rather, an insignificant variation in infiltration values of the upper, middle and lower slopes. Though the middle slope has the highest mean values than the upper and lower slope, this difference of variation is not that much. The result of analysis of variance of the transmission constant of the upper, middle and lower slope proves this, (See tables 3 and 4).

Table 2: Results Analysis of Variance Table Diffusion Constant

Source	Df	Sum of Squares	Mean Squares	F. Ratio
Between Groups	2	9.1993444	4.5996722	1.36
Within Groups	69	232.8176507	3.374168851	
Total	71	242.0169951		

The analysis of variance test of the transmission constant proves the significance of the transmission constant mean values for the upper, middle and lower slopes (Table 1 & 3) at the A.05% level. The calculated F-value is less or smaller than the tabulated F-value depicting that no two groups are significantly different at 0.05 level of significance.

Table 3: Analysis of Variance Table for Transmission Constant

Source	Df	Sum of Squares	Mean Squares	F. Ratio
Between Groups	2	1.12711178	0.56355589	1.49
Within Groups	69	26.01209542	0.37698689	
Total	71	27.1392072		

Table 4: Transmission Constant (MM) of the transects.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
UPPER	2.8	1.678	1.055	3.088	2.183	1.489	1.278	0.706	1.067	0.128	0.233	0.222	0.144
SLOPE	0.144	0.105	0.155	0.194	0.633	0.4	0.383	1.4	0.261	0.355	0.511	0.667	0.778
MIDDLE	1.111	1.222	1.056	1.722	1.167	1	0.833	0.272	1.055	0.2	0.58	2.556	1.167
SLOPE	0.617	1.389	0.572	0.383	0.489							x =	0.966
												SD =	0.571
LOWER	1.616	0.283	0.456	0.789	0.355	0.633	0.5	0.461	0.533	0.4111	0.533	0.6222	0.6
SLOPE	0.661	0.405	0.35	0.237	0.411	0.489	1.361	1.061	0.778	0.355	1.6	1.322	1.044
	0.111	0.55									x =	0.662	
											SD =	0.401	

The Mean Infiltration Capacity of Slope

It is necessary to distinguish between two types of mean values referred to in this section. There is the mean of the infiltration capacities for an experimental site. This is the sum of the minute by minute infiltration capacities, divided by the total number of minutes for which the experiment was performed at a particular site. Since the experiments were performed at 72 sites in the hillslope area under study, these were separated into the slope type (i.e. upper, middle and bottom slopes), to which they belonged. For example, the upper slope had 26, the middle slope had 18 and the bottom slope 28 (see Table 5).

The other mean, henceforth referred to as surface type sample mean, is the mean of the values from a slope type (i.e. whether upper, middle or bottom slopes). For example, the upper slope has 26 values on it as a surface while middle slope, another surface type had 18 values, bottom slope 28 values and the average of the set is the surface type sample mean. The surface type sample mean can also be referred to as the mean of means. Both the mean of data per site and surface type sample mean are considered in this section.

The surface type sample mean of infiltration capacity was calculated for the upper, middle and bottom slopes. The upper slope had a value of 3.60, while the middle slope had 3.54 and the bottom slope 2.51. These means distribution does not display a marked variation, (see Table 1). This tends to justify the assertion earlier on made, that slope has little or rather insignificant impact on water infiltration into the ground.

The results of the Analysis of Variance (ANOVA), computed from the data of mean infiltration capacity, was also used to establish the difference or variation in infiltration values between the upper, middle and lower slopes, since it is a statistical test that established the difference between three or more sample means as can be seen from the preceding discourse. The test considers all the deviations of members of a group from the group mean. These are known respectively as within and between group errors. Between variations can also be referred to as explained variables while the within variation as unexplained variables.

Table 5: Mean Infiltration Capacity (MM) Along the Transects.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
UPPER	10.8	5.7	4.10	9.75	8.19	5.9	5.74	2.37	3.28	0.29	0.68	0.59	0.41
SEGMENT													
OF	5.19	0.73	2.98	1.09	3.99	3.83	1.98	4.67	0.96	1.49	2.05	2.35	X =
SLOPE													3.564
													SD =
MIDDLE	5.06	3.98	3.61	5.07	3.94	2.7	2.97	1.38	4.49	0.27	1.48	10.9	2.904
SEGMENT													2.50
OF SLOPE	6.17	3.68	2.21	1.53	1.79							x = 3.538	
												SD = 2.393	
LOWER	3.42	2.13	1.84	2.85	1.16	2.89	2.68	2.33	1.57	1.57	1.67	2.14	1.58
SEGMENT													
OF SLOPE	2.01	3.47	0.92	0.65	1.53	2.91	5.42	5.6	2.09	0.96	5.01	5.57	3.92
	0.31	2.05									x = 0.662		
											SD = 0.401		

Table 6: Analysis of Variance for Mean Infiltration Capacity

Source	**Df**	**Sum of Squares**	**Mean Squares**	**F-Ratio**	**F-Prob.**
Between Groups	2	4463.8656	2231.9328	1.2733	.2865
Within Groups	68	119193.0006	1752.8382		
Total	70	123656.8667			

The table above shows the result of the F.test, of the mean infiltration capacity. The table value of 29.6044 at the 0.05 level of significance is greater than the F-calculated value of 1.2733. This result implies that there is no significant variation between the infiltration capacities of the upper, middle and bottom slopes along the toposequence. This then suggest that, whether or not infiltration is high is not only affected by slope alone, but may also be affected by other factors such as vegetation, landuse types, climatic elements and so on, as initially pointed out, Rauzi et al (1968); Blackbum (1975; Oyegun, 1994). From the table of analysis of variance, within class variation is lesser than between class variation as evident in the mean square value of 1752.8382 and 2231.9398 for within and between samples respectively. This shows that there are other factors that also have influence on water infiltration. It can therefore be pointed out from the preceding so far that there is no significant difference between the infiltration values of the upper, middle and lower slopes.

Infiltration Equation of Study Area

Talsma – Parlange equation was employed in this study because of its easiness of computation and also because time can be expressed as an explicit function of cumulative infiltration. This equation was applied to the data collected in the present study. Three infiltration curves resulted from fitting the Talsma-Parlange equation to the data, each representing a section of the slope (i.e. upper, middle and bottom slopes). These graphical representations are shown in figures 1,2 and 3. The infiltration equation shows a general rapid decay from high initial values and settle down to high final infiltration rates.

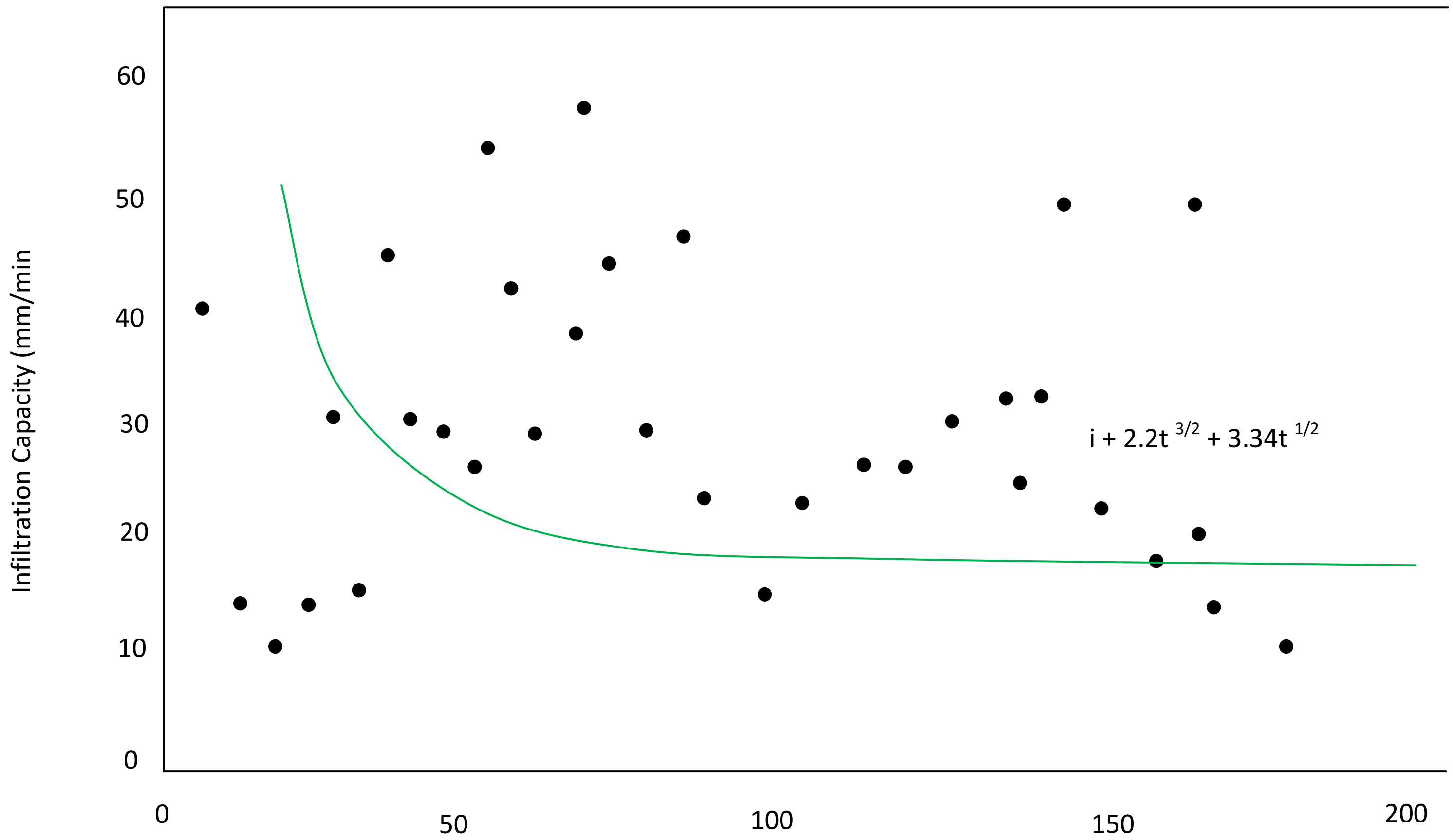


Fig. 1: Infiltration Equation Curves of Study Area: Upper Slope

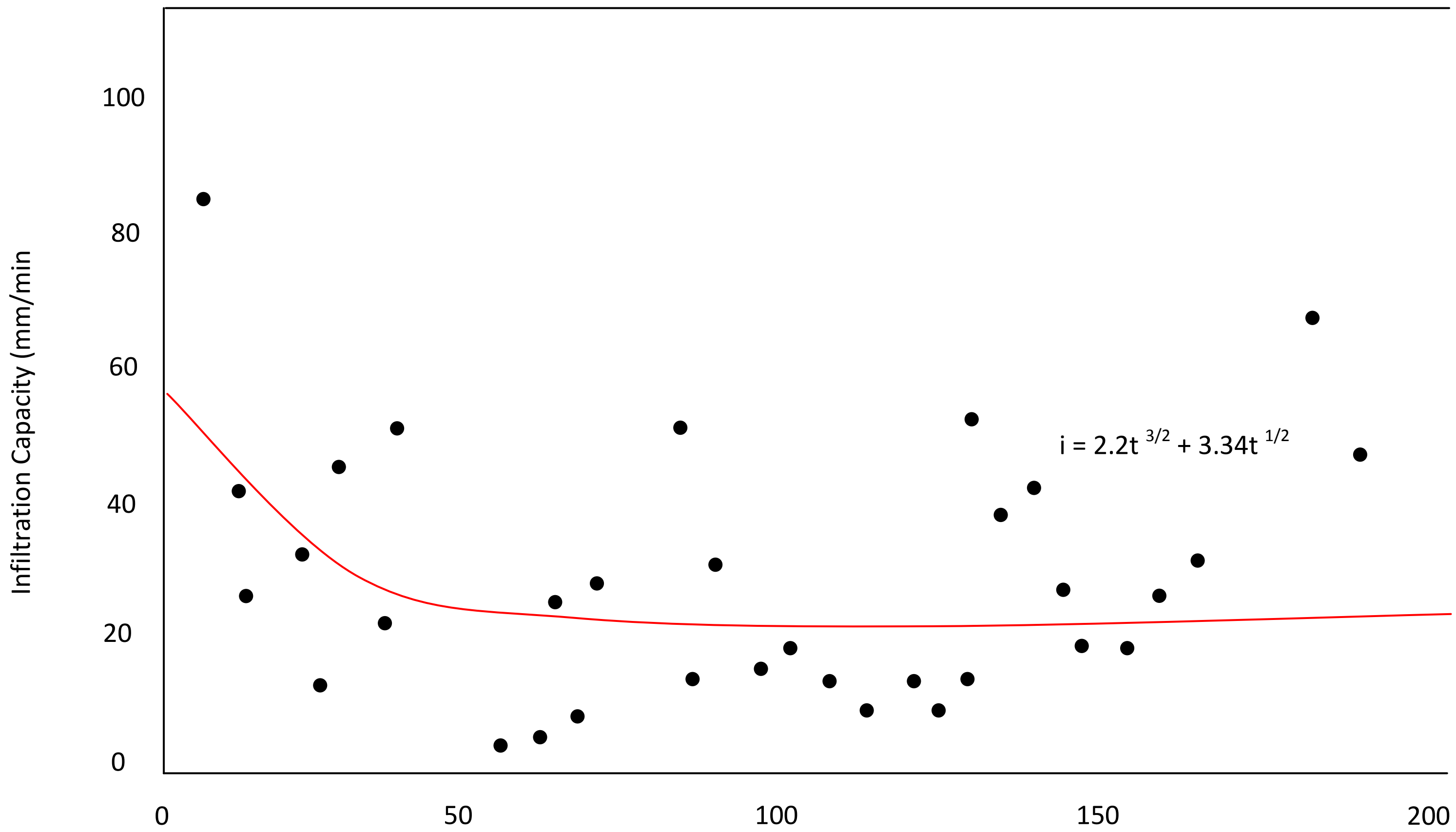


Fig. 2: Infiltration Equation Curves of Study Area: Middle Slope

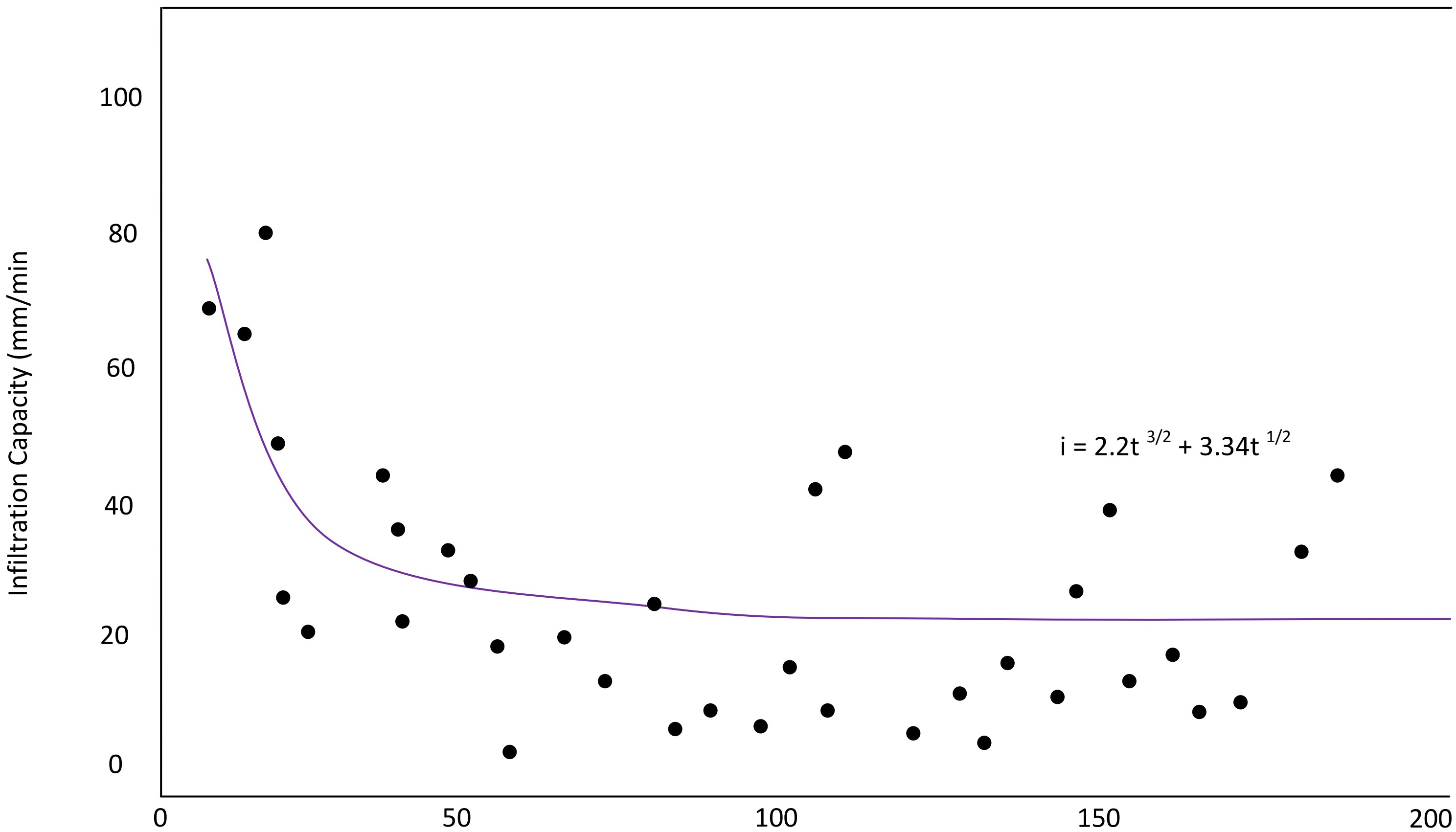


FIG. 3: INITIAL INFILTRATION CAPACITY SOIL MOISTURE

5. Conclusion

It is an undisputable fact that a major hindrance in run off prediction from watershed has been the characterization of the infiltration process which is excess of precipitation. This difficulty is due mainly to the variation from site to site in the field. To simplify the infiltration prediction researchers over time have introduced a number of algebraic infiltration equations. These equations range from physical based to empirical as much attention has been paid to the Philip two term equation which has an inherent problem of the uncertainty in estimation of parameter "A" which has to do with hydraulic conductivity. It was with this in mind that the Talsma-Parlange equation was adopted for use in the study and indeed it actually proved to be a promising model. From the explanations of the infiltration capacity curves derived from this study, the diffusion and transmission constants including the mean infiltration capacity, revealing or suggesting that slope does not have much of an influence on water infiltration as such, though it may influence it to some extent. That infiltration is high or low on a hill slope topography may as well be due to the influence of other factors such as vegetation, land use types, climate factors etc. other than slope alone.

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