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Overland (Surface) Flow and Time of Concentration for Highly Permeable Sandy Soil Slope: An Experimental Study Using Rainfall Simulator

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Abstract: ***Time of concentration is defined in many ways in literature and it is calculated rather subjectively in practice. The situation becomes adverse as the terrain slope reaches to zero; because the slope generally appears in the denominator of any formula for time of concentration, this time goes to infinity as the slope becomes zero. Estimation of it seems very paradox in nature (Grimaldi, 2012).The variables affecting this time parameter on highly permeable slope plot have been studied through plot scale laboratory experiments using rainfall simulator on artificial catchment prepared. It has been found that the initial moisture content and rainfall rate control this parameter. Some of the existing times of concentration methods have been compared, and it is found that the empirical models compared under predict this time parameter. This under prediction can be attributed first to the differing concepts of time of concentration previous researchers have been modeled, secondly to the absence of any accounting for the initial moisture content in the irrespective equations and thirdly to the watersheds where these models have been calibrated. At lower time of concentrations, Izzard-based model predictions show some results close as well as logical to the observed values. Regression equations have been derived based upon the experiments to determine the overland (surface) flow times on a plot of 2.02 meter length, 1 meter wide and 0.15 m depth soil plots of highly permeable natural sand (at the slope of 5 to 15^0 to the horizontal plane) with uniform rainfall intensity. The application of these equations on other lengths cannot be ascertained. Equations for the hydrograph have been determined for highly permeable sand plot. From the matrix solver for multiple regression analysis, regression model assumed and the exponents of the parameters are obtained as: 0.5 for length, -0.14 of rainfall intensity,-0.11 of surface slope, and -0.05 for initial moisture content for highly permeable sandy soil slope. The exponents seems very good adjustments to the previous results of the researchers for different terrain.***

Keywords: overland flow, Time of concerntration, regression corellation equation, highly pearmeable sandy soil slope

1. Introduction

Estimation of flood due to a rainfall event is a complex work in engineering. The calculation of the peak flood and its time of occurrence in a river basin are very important for the design of civil structures like dam, bridge, barrage, culverts etc[2]. Wrong estimation leads to the failure and collapse of the structures and may causes to loss of human life as well as huge physical loss of a nation. So real information is essential of a river basin or catchment area especially during monsoon period. High floods cause inundations in plain region. The problems due to high flood level and poor forecasting system has become a big problems to take precautions in poor countries as they are not able to afford huge money for the development of rigid structures stable against the flood and to develop reliable forecast system like in rich countries. For this the study of watersheds area, their physical conditions and properties should be well known for hydrological information. The characteristics of a water shade includes the soil type, slope, land cover, land use pattern and the location whether it is hilly area , plain region or mixed of both hill and plain. As our rivers are originated from Himalayan region and flows towards the plain region, the problems of the sedimentation erosion, transport and deposition is a main cause of inundations in plain where the soil deposited is sandy in nature. To estimate the peak flood and its time of occurrence which is known as time of concentration are carried out worldwide and many technique,equatios are developed for its calculations but still this is a paradox in nature as the equations available are suitable for a particular place as they are developed for that catchment area[3]. So therefore if we can develop the equations considering all parameters affecting to the time of concentration (Tc) would be better to estimate it for a particular soil type watershed area[4]. For this purpose this study is aimed to develop the correlation regression equation considering maximum parameters in sandy soil slope in an experimental basis in laboratory and the study aims the following objectives:

General Objectives

- To conduct the experiments under the different rainfall rate at uniform pattern, at varying slope, initial moisture conditions.
- To measure runoff at different time intervals and different initial conditions, to develop the hydrographs.
- To find out the rainfall runoff coefficient for the sandy soil slope and to compare with the rational values.

Specific Objectives

- To develop a regression equation for the rainfall and runoff for the soils profiles, to generate the correlation graphs.
- To validate the time parameter from hydraulic model, empirical model with the observed.
- To develop a regression equation for the time of concentration based upon the experimental data for natural sandy soil slope.

2. Governing Literature and Equations

This study work is completely experiment based. All the experiments are aimed to conduct over the catchment prepared within the laboratory set ups. Principally, whether the tests to be carried out follow up the fundamental principles of the hydrology engineering is the primary concerned. The relation between input rainfall and expected runoff are associated with the physical process that can be studied within the catchments from the artificial rainfall given. The subsurface runoff, its development process, time for the surface generation, and the time for the peak discharge are to be observed from the laboratory experimental approach. So therefore, the related literature are reviewed on the overland flow, the primary factors affecting for the time of concentration, the theory of physical process occurred in highly permeable natural sandy soil slope.

2.1 Overland Flow (Runoff)

Overland flow is generated by two mechanisms: infiltration excess and saturation excess. In infiltration excess, the rainfall rate exceeds infiltration capacity and this excess rainfall moves surface depending upon the topography. This type of surface flow usually occurs at places where water table is deep. Saturation excess surface flow occurs at a place where there is a shallow water table. In this type of surface flow, the cumulative infiltration depth exceeds the soil storage capacity, and the resulting excess saturation spills onto the surface as surface flow. surface flow depends upon slope, flow length, soil characteristics, shape of the watershed, surface roughness, and depth of water table and depression storage capacity of the watershed and rainfall intensity. Overland flow/runoff from here onwards refers to infiltration excess. During any rainfall runoff event, in the early stages because of high infiltrability of unsaturated soil, the whole rainfall will infiltrate (Akan 1986). With continuous rainfall soil infiltration capacity continues to decrease and then comes a stage when rainfall rate exceeds the soil infiltration capacity and this difference in rainfall and infiltration rates is available for surface runoff. Surface topography then guides this available water towards the watershed outlet. With continuous rainfall the whole watershed starts to contribute towards the runoff at the outlet; at time of concentration, the discharge is the peak discharge.

2.2 Overland Flow - Peak Discharge Estimation

Methods to calculate surface runoff can broadly be classified in two ways: Infiltration models and Rainfall excess models. Infiltration excess models calculate infiltration and whatever cannot infiltrates is estimated as runoff. Some of these methods include Green Ampt, Horton, and Holton methods. Rainfall excess models directly calculate runoff, e. g., SCS Curve Number Method. As peak discharge is generally required in most design analysis, there are some methods which directly calculate the peak discharge e.g. Rational Method and Graphical Peak Discharge Method.

2.3 Time of Concentration of Overland Flow

During any rainfall event, rainfall excess, i.e. rainfall minus infiltration and interception, first fills the depression storage then flows over land surface, then into shallow ill-defined rivulets, then shallow concentrated flow before entering a watercourse. Following the water course, the discharge reaches the outlet. Time of concentration is thus sensitive to all the above mentioned flow types. Time of concentration (Tc) has been defined in the literature as[5]:

The travel time of a wave to move from the hydrological most distant point in the catchment to the outlet. (Bedient and Huber 1988).The time to equilibrium of the catchment under a steady rainfall excess (i.e. when the outflow from the catchment equals the rainfall excess onto the catchment (Bedient and Huber 1988).USDA-NRCS (1986) defines time of concentration as sum total of travel times for sheet flow, shallow concentrated flow and channel flow.Time from the end of a burst of precipitation excess to the point of inflection on the falling limb of the direct runoff hydrograph (ASCE 1997).The duration required for runoff at the point of concentration to become a maximum under uniform and constant rainfall intensity (Hromadka et al. 1987).It is a complex job to estimate its accurate value and a paradox in hydrology [6]. Time of concentration estimation models/ methods has been classified in two ways: hydraulic and empirical estimations. Hydraulic estimation considers uniform flow theory and basic wave mechanics. Some of the models in this category are:

1) Velocity method (McCuen, 1998)

Mc Cuen (1998) developed an equation for the time of concentration in terms of velocity and length of the catchment. He assumed the catchment in number of grids and expressed the equation as:

$$Tc = \frac{\sum_{i=1}^{N} \frac{Li}{Vi}}{60} \tag{2}$$

Where, V is the velocity in fps, $V = k\ S^{1/2}$, N is number of segment, L is flow length in feet, S is slope. (i=1 to N denotes the number of grids along the catchment)

2) Izzard Gupta method (Gupta, 1989)

Izzard Gupta developed the equation for the time of concentration in 1989. His equation considers the intensity of rainfall, length of the catchment and rational coefficient. The elevation difference between the inlet point and outlet points is also considered as it determine the slope of the catchment. The equation is given:

$$Tc = (0.024i^{1/3}+878k/i^{2/3})L^{2/3}/C^{2/3}H^{1/3} \tag{3}$$

Where Tc is in hours, i is in mm/hour and L and H, the total drop in elevation) are in meters. Units will be changed to U.S. Customary later in the chapter. Converting our example to metric and taking C to be 0.95, t-c is 19.9 minutes.

3) Overton and Meados

McCuen (1998, p. 145) suggests a Welle and Woodward Kinematic simplification to avoid the iterative solution. Gupta (1989, p, 642) and Debo and Reese (1995, p. 234) attribute the model to Overton and Meadows. ASCE (1996, p. 565) calls the simplification the "New SCS" equation and limits its applicability to overland flow paths of no more than 300 feet,

$$Tc = \frac{0.42}{\sqrt{p2}}\left(\frac{(nL)^{0.8}}{S^{0.4)}}\right) \tag{4}$$

Where, P-2 is the 2-year, 24-hour rainfall depth.

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4) Izzard –Horton

The Izzard-Horton modification is similar mathematical appearance to Equation by (Ponce, 1989, p.139). Horton's approach lies in mass, not energy, flux. Eq. 16 is the theoretical time to equilibrium runoff t-e under uniform rainfall intensity i, a first approximation of overland t-c (Ponce, 1989, p.70).

$$Tc=2/i^{(1-1/m)}(nL/S^{0.5})^{1/m} \tag{5}$$

Where 'i' is rainfall intensity in mts. /hr. 'L' is in meters.

Empirical estimation which usually arrive from hydrograph observation and often (but not always) consider watershed as a whole, not as a sum of sequentially computed reach behaviors" (Heggen 2003). Some of the methods are:

5) Kirpich (1940)

$$T_C=0.0195L^{0.77}S^{-0.385} \tag{6}$$

Where,

T_C = time of concentration, in min

L = Length of channel reach, in meter

S = average slope of channel reach, m / m

For small watersheds (less than 5 sq. km area) Haan et al. modified this equation as,

$$T_C = 0.0195\ L\ 0.77\ S^{-0.385} + [2\ L_0.\ n / \square S_0]^{0.467} \tag{7}$$

6) Federal Aviation Authority (McCuen, 1998)

The FAA (Federal Aviation Authority) model, developed for airfields, is employed for urban overland flow (McCuen, 1998, p. 153; ASCE, 1996, p. 584; Viessman and Lewis, 1996, p. 318).Implication of government approval perhaps perpetuates the equation.

$$Tc=1.8(1.1-C)L^{1/2}S^{1/}3 \tag{8}$$

Where, L is length of flow in feet, s is in percentage and C is rational method coefficient (Mc Cuen, 1998)

7) SCS Model

The SCS model is employed by the Soil Conservation Service for both rural and urban watersheds up to 2000 acres (Mc Cuen, 1998, p. 153).

$$Tc = 0.00526\frac{L^{0.8}}{S^{0.5}}(\frac{1000}{CN} - 9) \tag{9}$$

Where 'L' is in feet, CN is the curve number (dimensionless).

8) Papadakos- Kazan

Papadakis and Kazan (1987) reviewed a number of times of concentration methods and found that these equations share the general format.

$$Tc=kL^a n^b s^{-y} i^{-z} \tag{10}$$

where Tc is time of concentration in minutes, L is the length of flow path in feet, n is the roughness coefficient, i is the intensity of excess rainfall in in./hr., S is the slope, k is constant and a, b, y, z are exponents. He formulated the model as:

$$Tc=0.66L^{0.5}n^{0.52}s^{-0.31}i^{-0.38} \tag{11}$$

9) ESpey – Winslow Model

The Espey-Winslow model was developed for Houston watersheds, urban and rural, of up to 35 Square miles (Mc Cuen, 1998, p. 152). The model is as:

$$Tc=31\ \Phi\ (L/S^{1/2})^{0.29}/Imp^{0.6} \tag{12}$$

Where, 'L' is in feet, 'S' is slope; Φ is the "channelization" factor which includes the amount of channel vegetation and the amount of channel improvement sand 'Imp' is percentage impervious.

10) Kerby-Hathway

The model for time of concentration developed by the Kerby- Hathway was used by McCune (1998) for his study. He has reported the model is useful for the small watershed area less than 10 acres. The equation is given:

$$Tc=0.83(n\ L/S^{0.47})^{0.47} \tag{13}$$

Where, L is in feet, S is in ft. /ft.' n' is Retardance coefficient Mc Cuen (1998). He noted that Kirby model was calculated at watersheds of less than 10 acres.

Assumed Regression Model for the Study in sandy slope profile

Draper and Smith (1998) were chosen to derive the influence of measured independent variables on the dependent variables, i.e., Time Parameters. A general regression equation is given as:

$$Tc=KL^a I^b S^c\ \theta^x\ FL^y\ dsc^z \tag{14}$$

Where, Tc is the time of concentration in minutes; L is overland flow length in meters; θ is the antecedent moisture content (gravimetric) in gm/gm; I is the rainfall intensity in mm per hour; S is the overland plane slope; FL is the Darcy-Wiesbach friction factor, dsc is the depression storage capacity calculated as per Onsted 1984.

2.4 Factors Affecting Overland (Surface) Flow

From the above literature review made on the time parameter, in both type of model i.e. hydraulic as well as empirical models, all have considered the effects of length, intensity of rainfall, slope of the terrain, runoff coefficients, roughness coefficients and the hydraulic retardance factor of the catchment soil. But the most important factors that cant are ignored for the exact computation of the time of concentration for peak flood and its occurrence is the initial moisture content by the soils in any catchment. Even Padadakis and Kazan has missed the effect of this parameter however his model is better than other that includes lot of factors that affect the time parameter directly. That's why the study is needed on the factors affecting the overland flows and its occurrences in the catchment due to rain. Some of the important phenomena are reviewed.

2.4.1 Infiltration

The rational method is a one-parameter model, i.e., time of concentration, as abstractions are accounted for in the runoff coefficient (Singh and Cruise 1989). The runoff coefficient 'C' vary during the rainfall duration and therefore do not physically represent infiltration (Smith and Lee 1984).Hjelmfelt (1978) in his mathematical model indicated the influence of infiltration on time of concentration. For overland flow generation, rainfall rate has to exceed the infiltration capacity of the surface soil, so for the same rainfall rate the time of concentration can vary significantly based on the surface infiltration capacity curve. Paintal (1974) also found that the time of concentration is governed by infiltration. Akan (1986) developed a mathematical formula based on kinematic overland flow and Green-Ampt infiltration, using Manning's roughness coefficient for time of concentration on a rectangular plane surface.

2.4.2 Rainfall Intensity/Duration

After comparing time of concentration methods using data collected from 48urban watersheds, Mc Cuen et al. (1984) found rainfall intensity is the most important input parameter. As can be seen in above equations for time of concentration, time of concentration is inversely related to this parameter. Singh (1976) stressed that rainfall duration has a definite influence on the time of concentration.[7]

2.4.3 Surface Slope

Runoff moves from higher to lower elevations. Slope controls overland flow velocities and hence overland travel times. Surface slope controls flow velocity (Manning's Equation). Darboux et al. (2002) investigated the overland flow triggering on numerically generated surfaces and found that the ratio of slope to random roughness is an important variable. In most time of concentration models, the slope term appears in the denominator if it appears at all, and any value of slope close to zero would give exceptionally high values for the time of concentration or exceptionally low values for the flow velocity, which contradicts common observations [6]. If all the Variables affecting the peak discharge are kept the same slope, time of concentration can vary significantly. In nature there commonly exist surfaces where average slope is quite close to zero.[8]

2.4.4 Roughness Coefficient/Flow Regime

The flow regime (laminar or turbulent) has also been found to affect the estimation of time of concentration, through its effect on the momentum transfer to the surface, and hence the value of the roughness coefficient. "For an overland flow with rainfall as the lateral inflow, the flow regime is complicated by the varying flow depth and velocity along the plane[9]. The flow regime thus becomes variable. For a plane that is sufficiently long, from the upstream to the downstream end of the plane, the flow regime may change from laminar through transitional to turbulent" (Wong and Chen 1997).Butler (1977) distinguished laminar overland flow to be flow with Reynolds's numberless than 1000 and turbulent otherwise. "Laminar overland flow with uniform width when analyzed as turbulent, the computed travel time is in error by

$$T \text{ laminar, true} = (K\ q\ )^{4/15} \text{ turbulent, false}$$

Where, the rate of discharge per unit width is q, K is a factor which varies with temperature, roughness and slope" (Butler 1982). Wong (2003) compared celerity and velocity based time of concentration of overland plane and time of travel in channel with upstream inflow. He found that average velocity time of concentration is β *(*ranges from 3.0 (laminar) to 1.5 (turbulent)) times longer than the average velocity base time of concentration for four flows (laminar to turbulent). Considering the above it can be concluded that time of concentration is sensitive to the flow regime, also there is nothing like a constant hydraulic resistance i.e. as hydraulic resistance changes with time and length of flow. Sellin et al. (2003) concluded that for vegetated flood plain a single Manning's' is inappropriate, it depends upon flow depth, velocity, vegetation type, density, dimensions, and flexibility which in turn depend upon age and season. So in the end it becomes necessary to choose an optimum/appropriate value for the roughness coefficient (Manning's 'n' or Darcy-Wiesbach 'f').

Manning's

$$n = \frac{\sqrt{S}\sqrt[3]{R}}{V} \tag{15}$$

Darcy-Wiesbach

$$f = \frac{8gdS}{V^2} \tag{16}$$

where, acceleration due to gravity is g, S is the slope, v is the mean flow speed, d is mean depth, and R is hydraulic radius.Sellin et al. (2003) reported that Darcy-Wiesbach friction factor recognizes different flow types based upon the Reynolds's number, so should be preferred for smooth turbulent or laminar flows and for fully turbulent, i.e., high Reynolds's number flows Manning's 'n' is preferable. Drunkenly (2002) stated that Darcy-Wiesbach 'f' can be used for both laminar and turbulent flows.

2.4.5 Depression Storage

Paintal (1974) reported time of concentration to be affected by depression storage. During any rainfall event, whenever the rainfall intensity exceeds the infiltration capacity of the soil, depressions on the surface begins to fill. A part of the rainfall thus stays on surface which ultimately either evaporates back into the atmosphere and or infiltrates. A lot of studies have been done to investigate the effect of this hydrological process on overland flow generation. Contrary to the belief that runoff begins after all depressions are filled; Hansen (2000) found that runoff starts before all the depression storage is filled. He also found that location of depressions also have a decisive influence on the precipitation excess required to all depressions. [7]

2.4.6 Antecedent Moisture Content

Surface soil moisture content is a state variable that is either simulated or required as input for many hydrologic models" (Hawley et al. 1983). The effect of this state variable was studied by Jacobs et al. (2003) on Little Washita watershed. They found the runoff measurement error (by SCS method) was reduced when they used remotely sensed soil moisture data on an 800 m grid as compared to 28 km grid. Merzand Plate (1997) investigated the effects of initial soil moisture and its spatial variability on rainfall runoff process and found that organization in spatial patterns of soil moisture and soil properties may influence the catchment runoff. Flat terrains are more amenable to variable source area and retain ground surface inundation for longer periods of time (Hernandez et al. 2003). In the light of above findings, the effect of this state variable on overland flow time of concentration, on surfaces with negligible slopes, should be given appropriate importance. Asch et al. (2001) also mentioned the importance of temporal and spatial distribution of soil moisture in top soil (0-5 cm.), that it affects runoff. [7] though experiments on Southeast Dartmoor, UK found that catchment response was relatively small (10% of the area) for initially dry state (low soil moisture and hence minimal lateral hydraulic conductivity) and large (65% of the area) for initially wet state (volumetric soil moisture content greater than 0.6 and rainfall events larger than20mm).He also found that antecedent moisture content influences the shape of a resulting hydrographs from a storm event. During wet conditions runoff mainly depends upon topography (Beldring et al. 2000).Akan (1986) combined the kinematic overland flow and Green-Ampt equations for a rectangular plot to develop a time of concentration chart for an infiltrating surface. It determines two time parameters, first the time when the surface runoff commences and the time to equilibrium (concentration). As Green-Ampt equation is used, effects of soil properties and antecedent soil moisture can be observed. He stated “the other factors are remaining the same, the time of concentration increases with decreasing antecedent moisture content”. [10]

3. Material and Methodology of Study

The study is completely primary data collection approach. The data collections are carried out from the experiments on the rainfall simulator of hydraulic Laboratory of Purwanchal Campus Dharan itself. The artificial catchment preparation of sand transported from river very used for construction work in eastern Nepal known as Gachhiya Khola located at Sunsari district, Province one of Nepal. The study follows the following flow diagram.

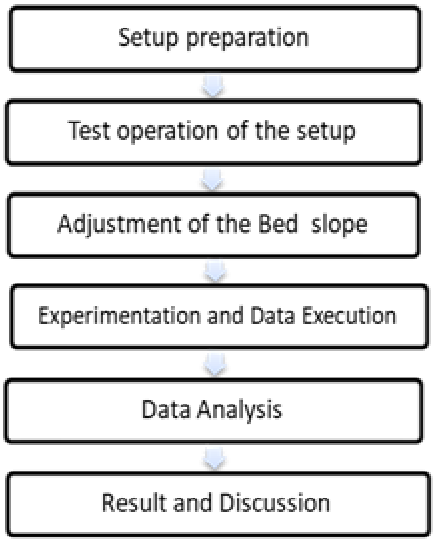

Figure 1: The flow diagram of the study work

3.1 Model Discription

The Rainfall Runoff Simulator model rig is used for the study. The simulator has a catchment tank for the artificial catchment preparation. The slope of the plot can be adjusted as per the requirement. This study is carried out at different rainfall rate and varying slope at different initial moisture content. The fig.2 shows the all components of the simulator. The technical specification of the model simulator is as Length: 2.2 m, Width: 1 m, Height: 0.2 m, Flow meter ranges 3-30 liters/ minute. The Electricity supply: 220 volt-240 volt/ single phase/50 Hz, for the sump motor. Hydraulic bench or cold water rainfall rate (3-30 liter /minute), well graded sand, Catchment Dimensions Length: 2.02 m, Width: 1 m Height: 0.15m.The total volume of soil used is of 0.30 $m^{3.}$

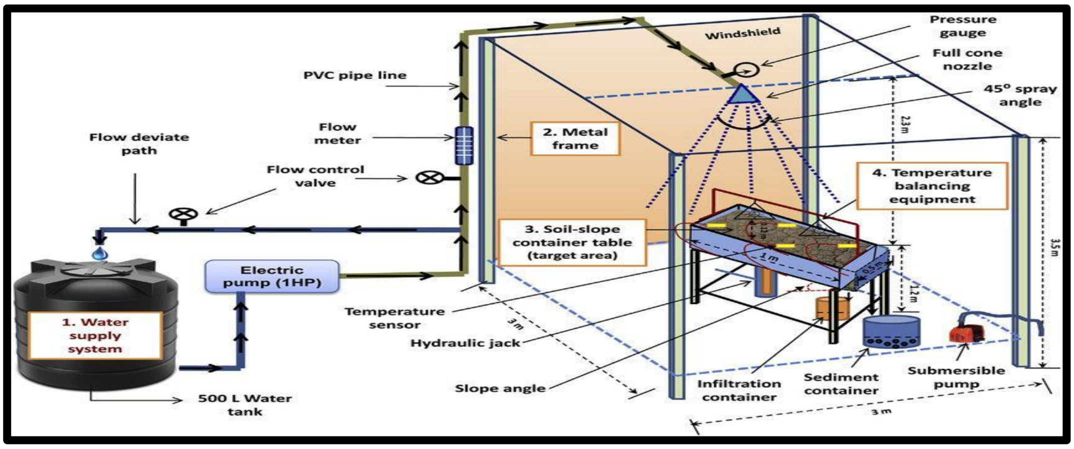

Figure 2: The schematic diagram of the model simulator

3.1 Catchment Preparation and Experiment observations:

3.3.1 Sand Catchment preparation

After sieving, the sand in the mixed form from the range of 0.2 to 2 mm was kept in the tank to form the catchment area. It was filled as per the specification of the user manual and marked line within the tank of total area 0.202 m^2 and volume of 0.3 m^3. As per our requirement, the slope was adjusted 5-15 degree with the horizontal plane. After the reconnaissance, detailed leveling was done by trial and error method so that accuracy was maintained. As all facilities for controlling, collecting, and runoff reading facilities are already associated became easier to observe, collect and measure runoff. Time observation was done by stopwatch provided. After the completion of the profile preparation the test were carried out and data recording were done simultaneously. As our main aim was to observe the instantaneous runoff discharge, time of concentration and peak discharge due to the different rainfall intensities from 3 l/min to 13 l/min was recorded. The figs 3,4 and 5 shows the catchments ,experiments observations and data acquisition in the laboratory.

Figure 3: The sand catchment preparation in the simulator at hydraulic laboratory

Figure 4: Manometer set for pressure measurement developed in the soil due to rainfall

Figure 5: Moisture content determination (soil laboratory, purwanchal campus Dharan)

4. Result and Discussion

4.1 Rainfall –Runoff Hydrographs

For soil profile of sand at wet condition under the same room temperature of 20^{oc}, the rainfall at the rate of 5 lph was given and the runoff in lps was recorded at the time internal of one minute with the help of stop watch. The rainfall was given in soil plot up to the peak discharge were obtained and simultaneous time for peak discharge was recorded that is the time of concentration for that given rainfall. For the uniform rainfall of 5 lpm, the hydrograph for soil profile are shown in (figs5). It was observed that the peak discharge value of 0.13 lps at the saturated condition was obtained at which the moisture content by each type of soil was 0.40 and the initial moisture content was 0.18 .After peak discharge the rainfall was stopped and the recession limb lowered down rapidly at which the minimum discharge was recorded 0.023 lps at time 25 minute time elapsed.

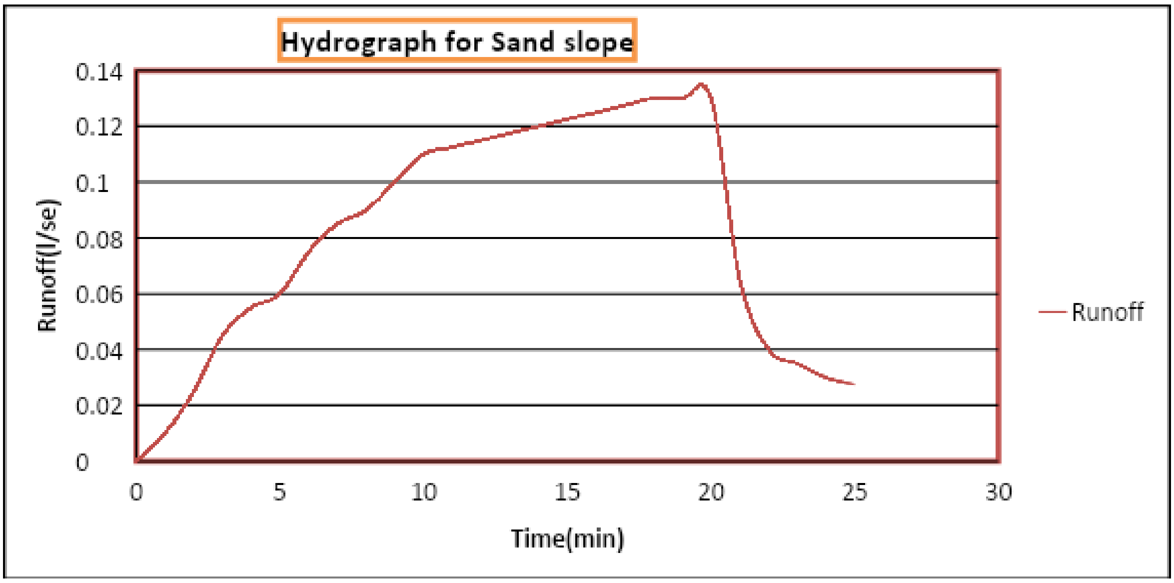

Figure 5: Hydrograph for sand plot

4.2 AMC Affecting Time of Concentration

Sand plot was tested with higher antecedent moisture contents at the rain of intensity of 5 lpm, little variation had been noted (Figure 6). Time of concentration had been found to be directly proportional to the combined effect of antecedent moisture and rainfall intensity. Sand with different antecedent moisture contents 18 %, 19.5%, 30.75%, 32.2% and 33 %, and consequence time of concentration was observed to be 18, 15.5, 13.5, 11.75 and 9.5 minutes. The relation obtained is as:

TOC = $69.60\Theta^{-0.05x}$ (R^2 =0.994)

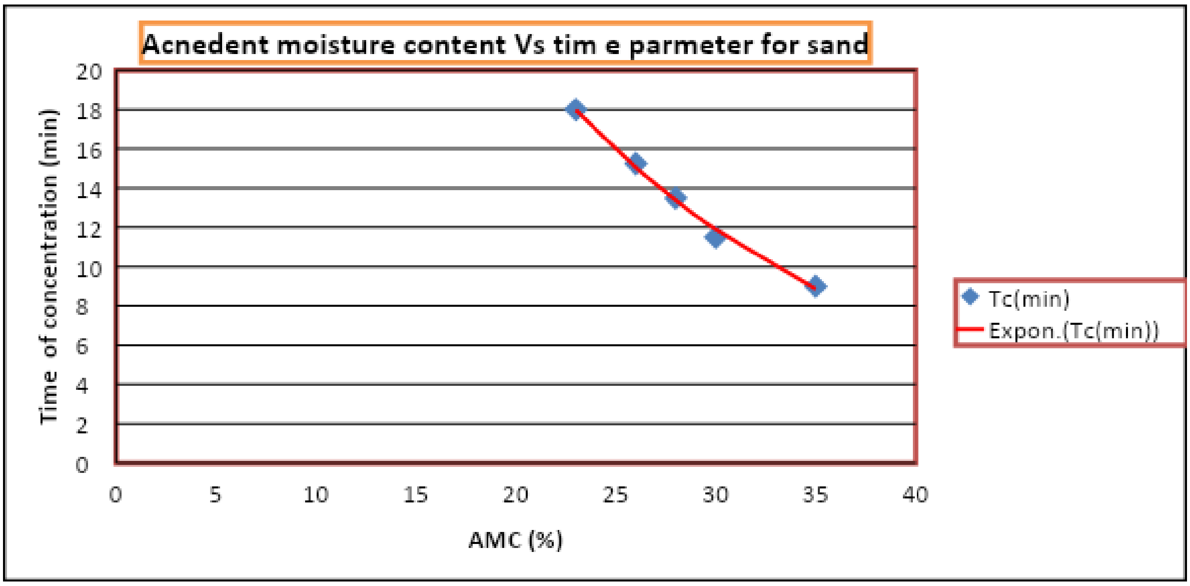

Figure 6: IMD vs TOC correlation

4.3 Rainfall intensity and Time of Concentrations

From the test conducted, the time of concentration was varied for different rainfall rate. The figure 7 is the rainfall rate vs time of concentration graph obtained .Time of concentration at peak discharge were recorded at constant rainfall rate of 5lpm and slope of plot 10 degree with the horizontal. The correlation equation was as given below.

For sand slope, TOC = $33.70i^{-0.17x}$ (R^2 =0.986)

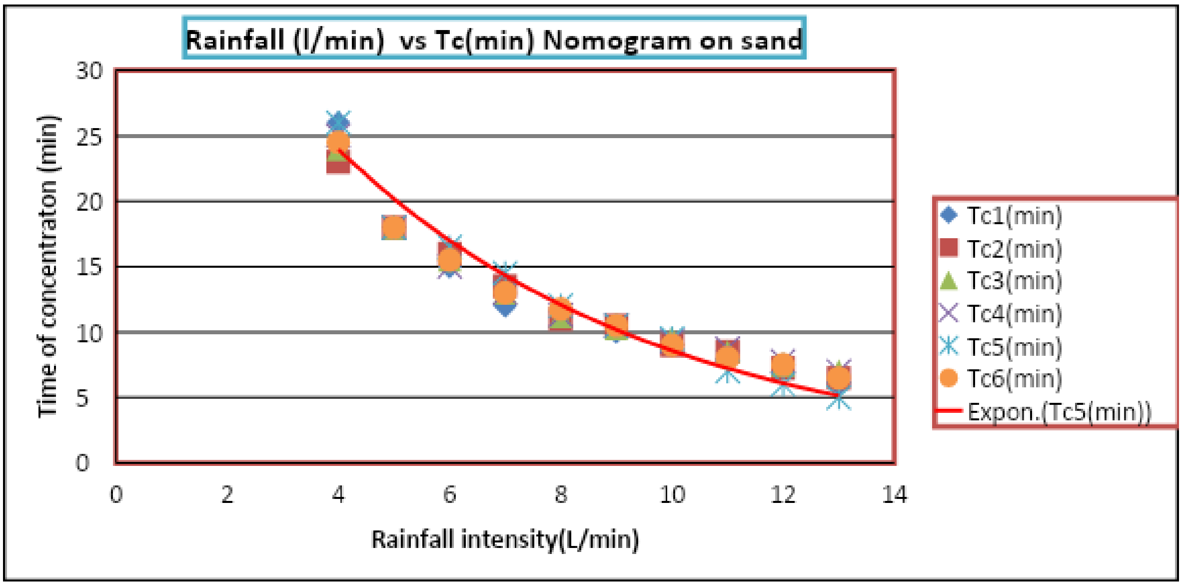

Figure 7: Rainfall vs TOC nomogram f or sand plot

4.4 Rainfall –Runoff Correlation

For soil slope the rainfall was given at the rate of 4 lpm to 13 lpm. Their peak discharges were recorded and the time of concentration was also observed simultaneously figure 8 shows the individual and comparative results of the observations sets. Their resultant rainfall- runoff relations for the best value of correlations were obtained as:

For sand slope, Y = - 0.00x^2 + 0.037x – 0.039 (R^2 = 0.997)

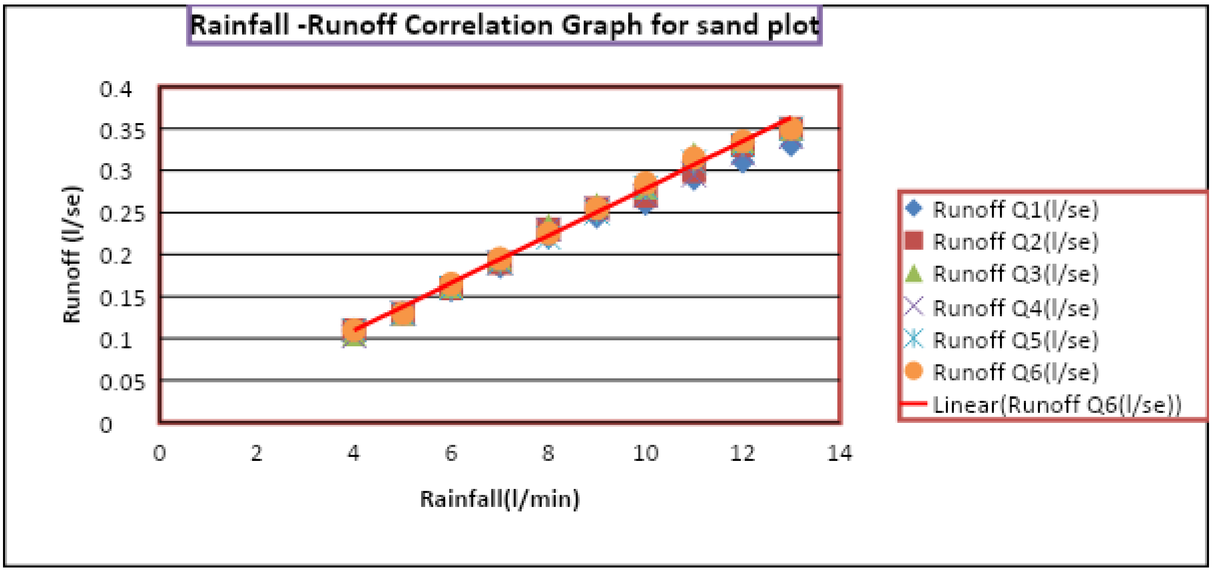

Figure 8: Rainfall-runoff correlation for sand soil plot

4.5 Hydrograph Slope

All surfaces generated different shapes for their hydrographs. If the time of beginning and time of concentration is known, assuming a linear hydrograph and slope of the hydrograph in degree as:

$$\text{Slope}=\frac{\frac{Q}{4.546}}{TOB\ to\ TOC}\Big)\frac{180}{\pi} \tag{16}$$

A linear relationship between the slope of the hydrograph and the rainfall rate in lpm (fig9) has-been observed. The Slope variations obtained for each soil slope were as:

For sand, Slope= 2.33i−8.871, (R^2=0.971)

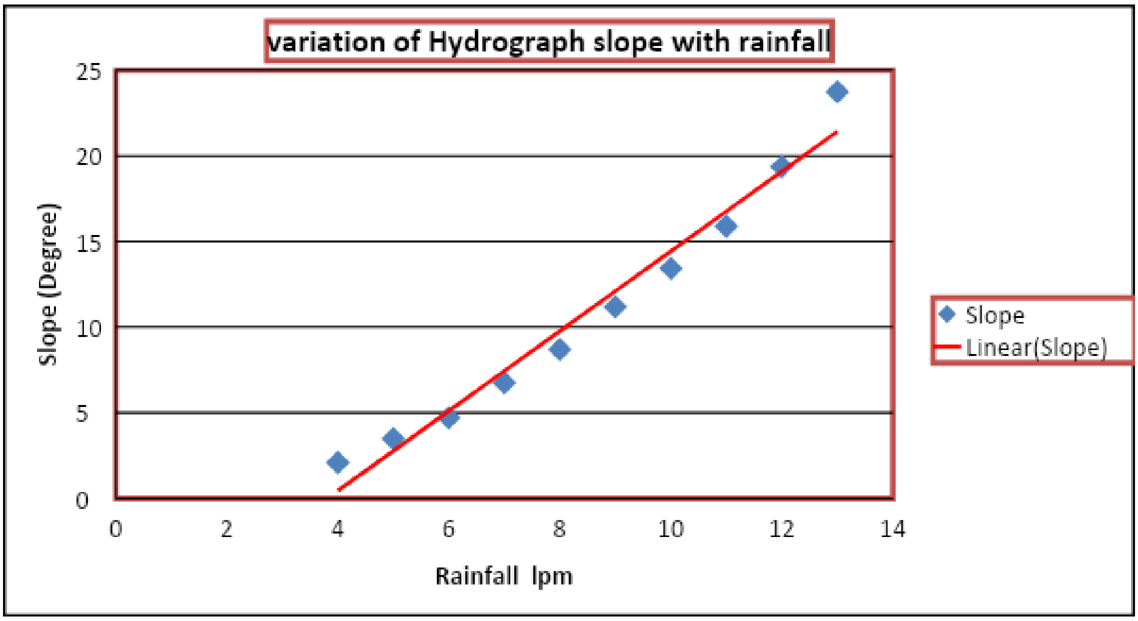

Figure 9: Variation of slope of hydrograph for sand plot

4.6 Variation in the Runoff Coefficients

For the computation of the runoff coefficient C, in soil profile for the given rainfall intensity, Rational equations were used. There has been a good deal of variation noted in the values of the runoff coefficients for surface (fig10). The runoff coefficients arranged in order follows as sand. The runoff coefficients lie in the ranges as reported in the literature (i.e. from 0.05 to 0.95). Fig. is the results of the runoff coefficients. The values of runoff coefficients were obtained in the range of 0.4 to 0.52.

Table 2: Observed and rational value of runoff co efficient for sand plot

Soil type	Observed C	Rational values C
Sand	0.428 -0.53	0.05 – 0.95

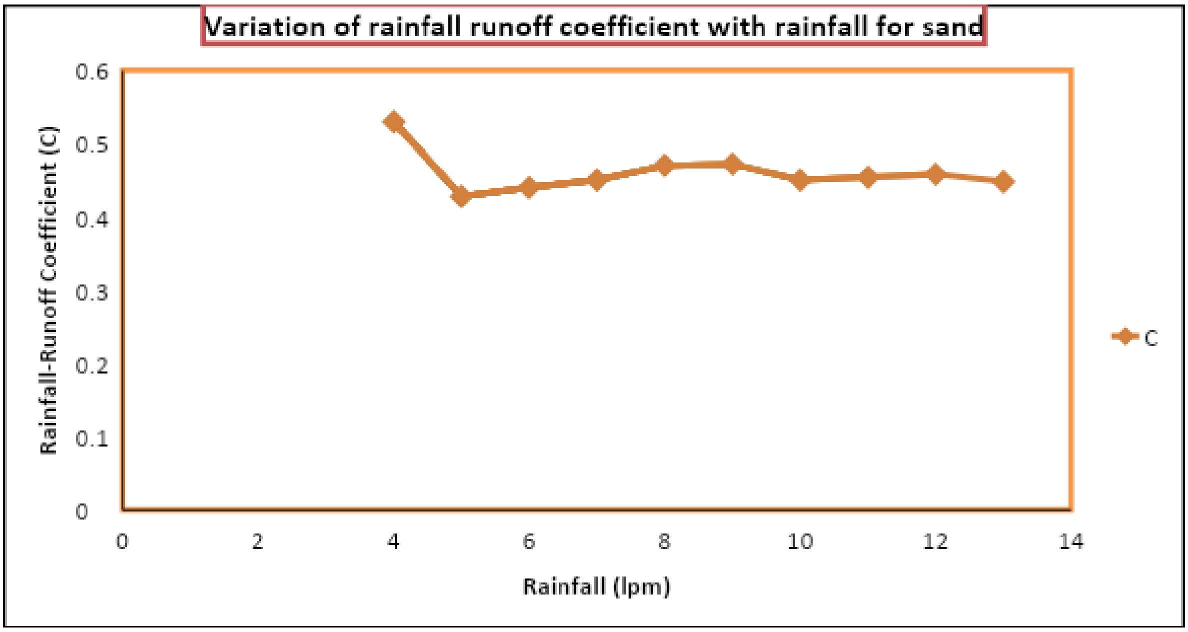

Figure 10: Variation of runoff coefficient on the plot from rational equation

4.7 Time of Peak with Slope

As described in the literature section 2.4.3 time of concentrations varies inversely with the slope of the surface. From the experiments carried out at the slope of the 5°, 10°, and 15°. The correlation graphs for e soil profile were found as in figure 11 and their equations were as:

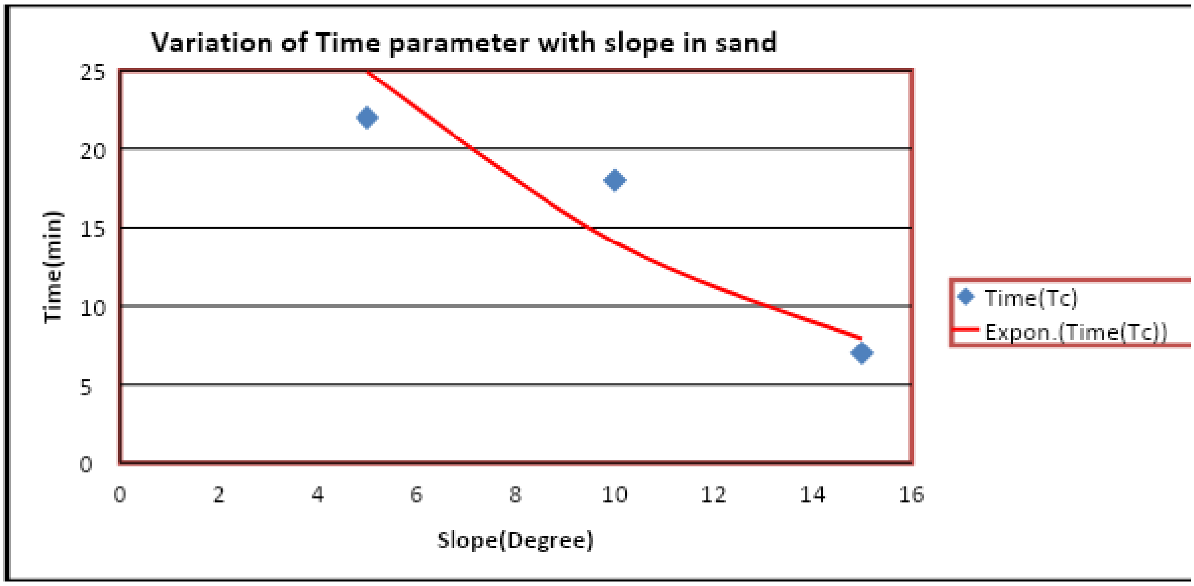

Figure 11: Slope vs TOC correlation

4.8 Comparison of Different Time of Concentration Models

Some of the commonly used times of concentration models have been compared with the observed data sets .Their resultant graphs are (figs 12 ,13) from which the Following observations were concluded:

1) There has been substantial variation in the predicted time of concentration by different methods. This variation can be firstly due to the fact that different models have been calibrated on different watersheds, as an example Kiprich (1940) calibration came out with different exponents/constants for Pennsylvania and Tennessee watersheds and secondly these existing models are based on different definitions.
2) Most of the empirical models under predict the time of concentration, which limits their application on flat terrains.
3) The sensitivity of the initial moisture content towards the time of concentration is missing in the models compared.
4) Most of the models have good results for the lower time of concentrations.

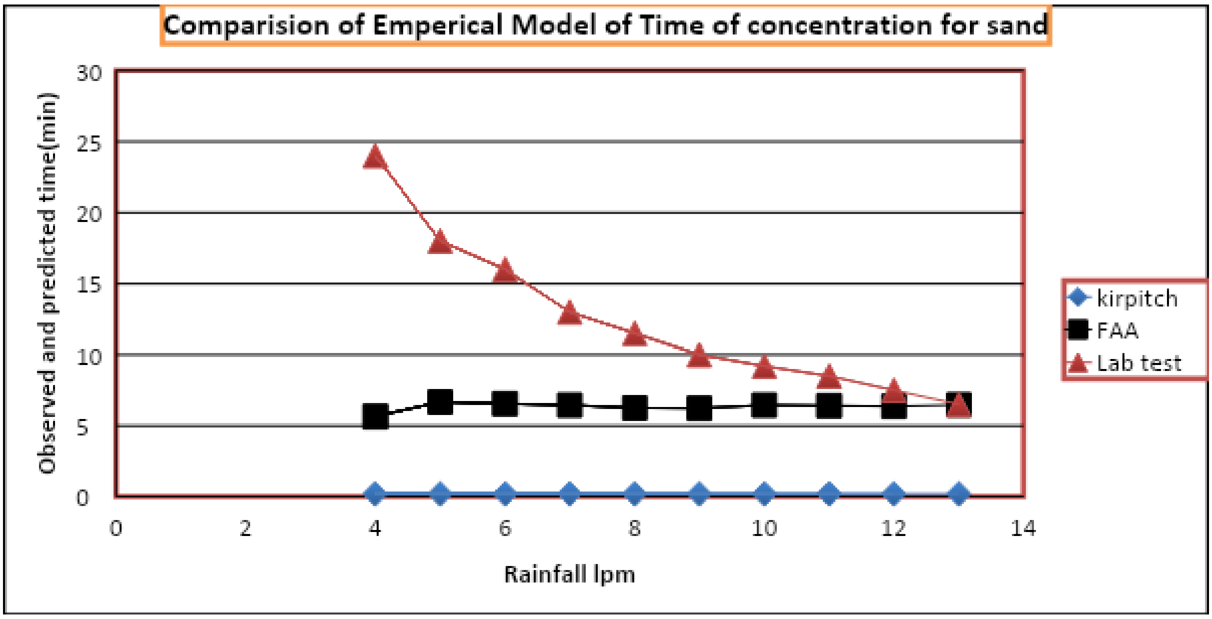

Figure 12: Comparison of empirical models of TOC for sand plot

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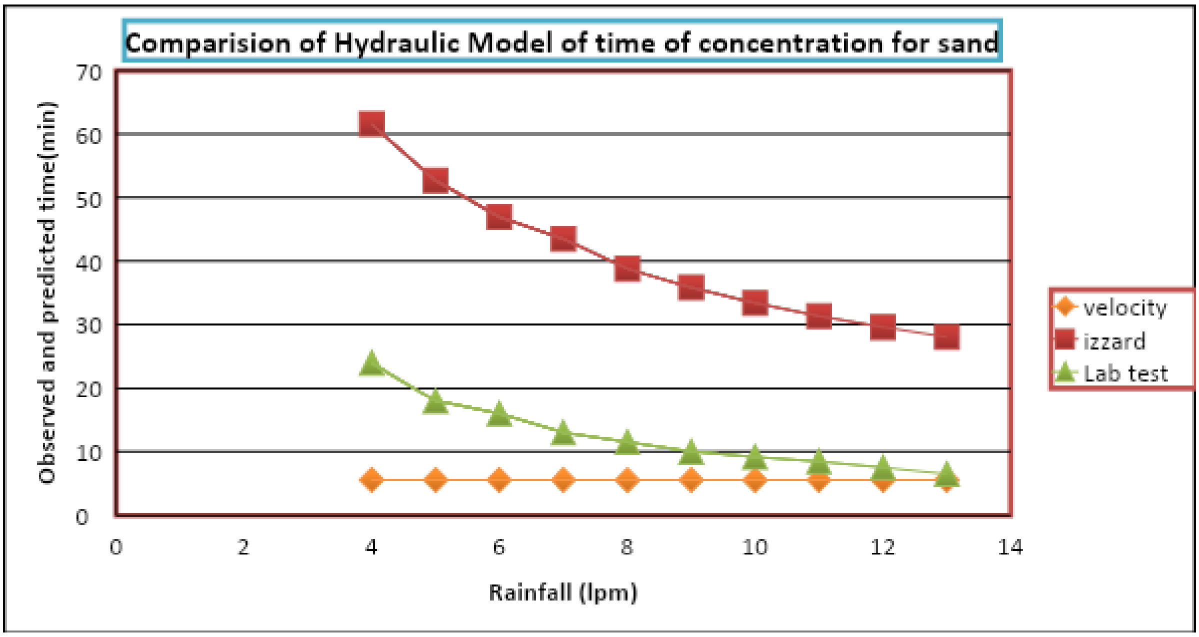

Figure 13: Comparison of TOC of hydraulic models for sand plot

4.9 Moisture Profiles

The comparison of moisture profile for sand of sizes 0.2mm , 0.125mm (mix and fine), and silt of size 0.06 mm over the depth was found as shown in fig14. It was observed under the intense rainfall rate of 15lpm for 5 minute at which the overland flow occurred. Since the infiltration capacity of the fine and mixed sand was high due to the larger size macropores, significant moisture transaction took place within the pores resulting the complete adjustment of the moisture. The percolating rate in the larger size of the pore was high so the high moisture content was measured at the mid of the mixed sand .However, in silt an appreciable amount of moisture percolates down as its macropores got saturated more than in sand so the moisture profiles for silt differed from the sand having the high moisture content in the top surface and low at the bottom. The moisture contents were measured just after the rain in all soil slopes. Owing to the low depth, the moisture profiles obtained are not exactly alike as found in the hill slope runoff process as explained by Shakya (1995) .However; it has followed the trend.

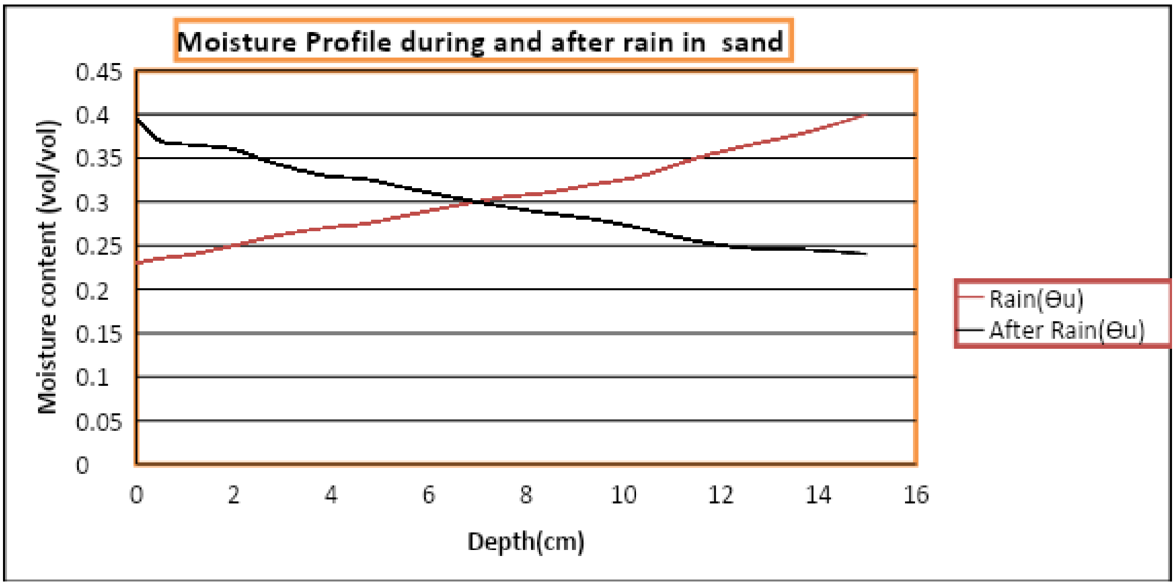

Figure 14: Variation of moisture profile for sand plot

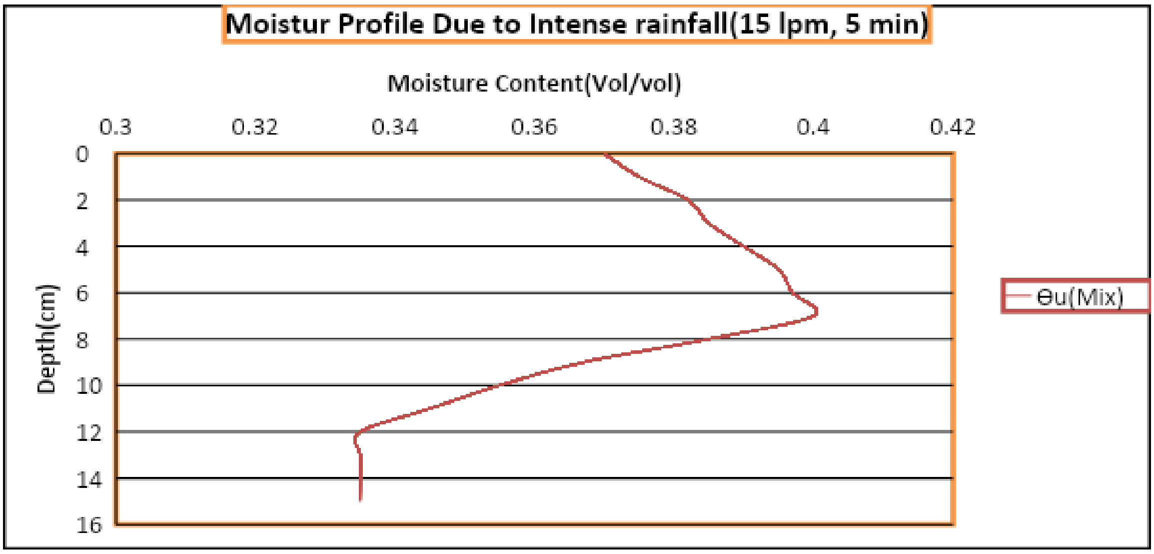

Figure 15: Moisture variation in sand soil slope due to intense rainfall

4.10 Regression Results

From the observation, the regressions equation obtained separately .The dependency of the time of concentration on the parameters intensity, initial moisture content and slope (geometry) variation are the governing factors. The exponents/constants of each parameter are shown in table. The time parameter could not be expressed in terms of the Darcy- weichback friction factor and depression storage due the nature of the developed catchment. But the exponent for the length and hydraulic retardance factor was taken from the Padadakiz- Kazan as he had carried the experiments out at 62 different soil terrains as mentioned in literature review.

Table 1: Regression Analysis Coefficients for Different Surfaces and Time Parameters

Surface Type	Time Parameter	Dependent variables				
		k	a	b	c	x
Sand	TOC	0.66	0.5	-0.14	-0.11	-0.05

From the regression analysis, i.e., from Table 1
1) Surface slope has low exponent/constant value.
2) Initial moisture content controls the time of concentration.
3) Rainfall intensity (within the range tested) affects (inversely) the time of concentration.

The multiple stepwise regression models on Draper and Smith model was obtained as:

$$T_c=0.66L^{0.5}I^{-0.14}S^{-0.11}\Theta^{-0.05} \quad (17)$$

From the model obtained, it could be concluded the dominancy of the intensity of rainfall was high. The initial moisture contents seemed sensible for controlling the time of concentration in any catchment .That is why its effects cannot be ignored for the computation of the time parameter in the catchment. For this stepwise regression model the regression statistics were as given in the table.

Table 2: Regression summary of the sand Plot experiment

Surface Type	Time parameter	Regression Analysis summary			
		R square	Standard Error	F	Significance F
sand	TOC	0.99	0.0345	1575.377	0.000634

5. Conclusions

On the basis of the observations tests, the results strongly indicate the importance of the hydrological processes (rainfall intensity, rainfall rate, and patterns), surface characteristics (geometry) and the antecedent moisture conditions. The major and significant results obtained from this study are outlined as followings:

There exist a variety of definitions for the time of concentration. In the absence of a clear definition of which "time" is desired or used in a specific application, experimental results may be difficult to compare to theory.

Most of the empirical models found in the literature which were compared in this study under predict the time of concentration parameter. Hydraulic Models are better than empirical models for the time of concentration analysis for each soil type.

Results show correlation between the rainfall intensity and the runoff coefficient.

Initial Soil moisture plays the vital role for the time parameters, runoff coefficients and hydrograph slopes for soil of the catchments.

The exponents of the parameters affecting time of for the plot tested are in well trends to the previous results given by the researcher [1]

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