Response Of Stream Discharge To Storm Depth In Gidan Kwano Inland Valley 0f Minna Nigeria

Enokela, O.S[1] and N. A Egarevba[2]
1 Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi-Nigeria.
2 Department of Agricultural Engineering, Federal University of Technology Minna-Nigeria

Abstract; Stream discharge and soil characteristics were evaluated on an experimental field for ten months. Calibrated rectangular weir was used to monitor stream discharge and sieve analysis was used to characterize the soil. Findings indicated a sandy loam, clay loam, and clay soil types at 0-60cm, 60-90cm, 90-120cm profile depths respectively .A range of 6.29 - 27.75%, 1.04 – 1.80g/cm^3 , 15.19 – 49.42% and 8.38 – 34.74% were established for moisture content, bulk density, porosity and available moisture content respectively down the profile (1 – 120cm) .Infiltration decreased from 0.2 to 0.07 cm/min and 0.25 to 0.025 cm/min at lower and upper fringe of the valley respectively. Stream discharge is highest in October with peak value of 41.897l/s and monthly average of stream discharge was 12.641l/s with only 67.7% of the storm depth translating to stream discharge. The discharge hydrograph exhibits a close nested multi-peak. These finding therefore, are viable information system for irrigation and drainage practices on land and also useful in land and water resources planning.

Keywords; Soil, Storm depth, Discharge, Water, and Inland valley.

I. INTRODUCTION

In undeveloped watersheds, soil type, vegetation, and slope all play a role in how fast and how much water reaches a stream. In watersheds with high human impacts, water flow might be depleted by withdrawals for irrigation, domestic or industrial purposes [1]. Dams used for electric power generation may affect flow, particularly during periods of peak need when stream flow is held back and later released in a surge. Drastic alteration of landscapes in a watershed such as urban development can also change flow regimes, causing faster storm events and higher peak flows due to increased areas of impervious surface. These altered flows can negatively affect an entire ecosystem by upsetting habitats and organisms which depend on natural flow rates. Tracking stream flow measurements over a period of time can give baseline information about the stream's natural flow rate.

Precipitation is the primary factor that contributes to stream flow because it usually provides the greatest percent of water for streams. After a rainstorm, stream flow follows in a predictable pattern where it rises and then falls in the hours and days following the storm. Although a sustained portion of stream discharge (Base flow) is drawn from natural storage sources such as groundwater and not affected by human activity or regulation [2]. Shallow Groundwater, springs, Lakes, Adjacent Wetlands and Tributaries all may contribute portions of the total flow in a stream and can be crucial during dry times. The steeper the gradient (or slope), the faster the water flows.

Vegetation along the banks and within the floodplain intercept rainfall, absorbs water from the soil and releases it to the air through evapotranspiration while the deep roots increase the water storage capacity of soil. This action of vegetation influences year round water availability and the volume reaching water table and streams.

When vegetated areas and wetlands are converted to bare soil and/or impervious surfaces the volume and velocity of runoff increases dramatically during storm events. Impervious surfaces include any surface that impedes the infiltration of water, such as streets, parking lots or rooftops. Therefore, during wet periods, a loss of vegetation and wetlands results in an excess volume of runoff that moves at a higher velocity. When precipitation has fully satisfied the demand of evaporation, interception, infiltration, surface storage, surface detention and channel detention, Storm event that increases stream channel discharge will occur [3]. Stormwater that does not infiltrate into the ground becomes surface runoff, which flows directly into surface waterways or channeled into storm sewers, which eventually discharge to surface waters. Stormwater is also a resource and ever growing in importance as the world's human population demand exceeds the readily available water [3].

Integrated water management (IWM) of Stormwater has the potential to address many of the issues affecting the health of waterways and water supply challenges facing the inland valleys and the settlers. It has the potential to improve runoff quality, reduce the risk and impact of flooding and deliver an additional water resource to augment potable water supply [1]. The development of a modern city often results in increased demands for water supply due to population growth. The altered runoff predicted by climate change has the potential to increase the volume of Stormwater that can contribute to drainage and flooding problems. IWM offers several techniques including Stormwater harvest (to reduce the amount of water that can cause flooding), infiltration (to restore the natural recharge of groundwater), biofiltration or bioretention (e.g., rain gardens) to store and treat runoff and release it at a controlled rate to reduce impact on streams and wetland treatments (to store and control runoff rates and provide habitat in urban areas)[4].IWM as a movement can be regarded as being in its infancy and brings together elements of drainage science, ecology and a realization that traditional drainage solutions transfer problems further downstream to the detriment of our environment and precious water resources[5]. According to Christine at-al [5] changes in streambed hydraulic conductivity with time, as a function of channel discharge by differential gauging is useful for determining the net change in discharge, as informed by the movement of water back and forth between the channel and nearby subsurface.

The West African Rice Development Association [6] defines inland valley as upper reaches of river systems in which alluvial sedimentation are completely or almost absent. They are valley bottoms submerged for period of years. They form hydromorphic fringes and its contagious upland slopes and crest extending over areas that contribute runoff and seepage to valley bottoms.

Inland valleys constitute important agricultural and hydrological assets at Local and National levels and can make a major contribution to food security and poverty alleviation. They cover approximately a hundred and ninety million hectares (190 Million ha) of land in sub – Sahara Africa [7]. Only a small area probably less that 15% of these great inland valleys, are presently utilized especially in sub-humid and humid zones. Despite this percentage, crop yields are still constrained by lack of appropriate water resource management, weed problems, lack of labour, human diseases associated with low land event, land tenure system and limited access to input and output market.

In this study series of experimental methods were used to effectively determine the nature and types of existing soils, volume of storm depths, volume and extent of stream channel discharge as necessity for water resources and land planning in the inland valley.

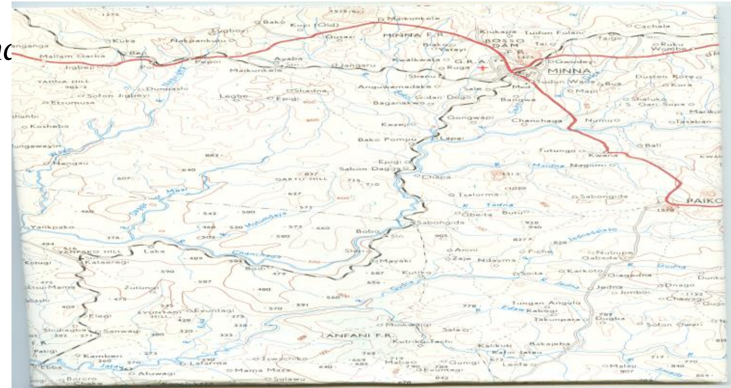
II THE STUDY AREA

The Gidan Kwano inland valley is located in Niger State between latitude $9^{o}15^{I}$ - $9^{o}45^{I}$ N and Longitude $6^{o}15^{I}$ – $6^{o}45^{I}$ E (Fig 1).of Nigeria. Only 10% of this area covered is currently being cultivated [7]. The problem in this valley has been variation in hydrology that creates seasonal scarcity of water as most of the rivers dries up during dry season and reappears again at commencement of rain. At peak of rain, runoff and flooding of farm produce result or culminate in the problems.

Gidan Kwano inland valley of Minna, Niger State of Nigeria represents an important underutilized resource of Nigeria agricultural production. It is characterized by favourable climate, deeply drained landscape element with sandy slopes and shallow impermeable layers and clay valley bottom. It is of great economic importance for both agriculture and settlement.

Water which plays a key role in the activities of mankind has been a problem to the inhabitants of the valley and even the university community. Water is either not available or when excess in circulation constitute environmental hazards to crops, livestock and properties. The impediment of water became worsened in the valley due to variation in rainfall distribution. This, therefore, informed the concern to evaluate the occurrence and distribution of water on the surface and underground within the valley.

The significance of this area derives from its sparse population density of 20 – 50 persons per square kilometer as reported by [9]. This population confirms the 2,421,581 total population figures occupying the 13,930km^2 of land area [9]. These figures represent 2.7% and 8.0% of the total population and landmass of the Federal Republic of Nigeria. This population distribution has left enough proportion of the inland valley for agricultural and other economic uses. Moreover, this few population of people that settled in the valley are predominately rain fed agriculturist and nomads. Common crops such as yam, rice, millet, melon, sorghum, cassava are grown at peasant level while animals like cattle, donkeys, goats, and chickens etc are domesticated. These group, though peasant still produces enough crop and dairies that feed the neighboring urban centers of Minna, Kaduna, and Abuja (the capital city of Nigeria)



9^{O} N 6^{O} E 9^{O} N 7^{O} E

Fig 1: Topographical Map of Minna showing the study area [8]

III. FIELD EXPERIMENTS / COLLECTION of DATA

The infiltration characteristics of both the upper and lower fringes were conducted using cylinder infiltrometer. The hydraulic conductivity of the soil at both upper and lower fringes were determined using equation 1

$$K\theta = \frac{-L\Delta\theta}{\Delta t} \text{-----------------} 1$$

Where L= thickness of profile in cm, t = time in hour and θ = average water content of soil

Profile pit were dug to collect soil samples at every 30cm up to 200cm in attempt to determine the soil properties and also characterized to determine its textural class.

A rectangular weir of crest L = 100cm was constructed using (120 x 240) cm^2 x 1,2cm laminated ply wood (fig 2). A meter rule staff gauge was also used and the instrument calibrated for reading the head of water.

The staff was installed by pressing it down into the channel base using wooden mallet. Clay materials were used to reinforce the weir by pressing hard to avoid water leaking through underneath and side ways. Wooden pegs were used to support the weir at the back as an additional reinforcement against the built up pressure from the Ponded water.

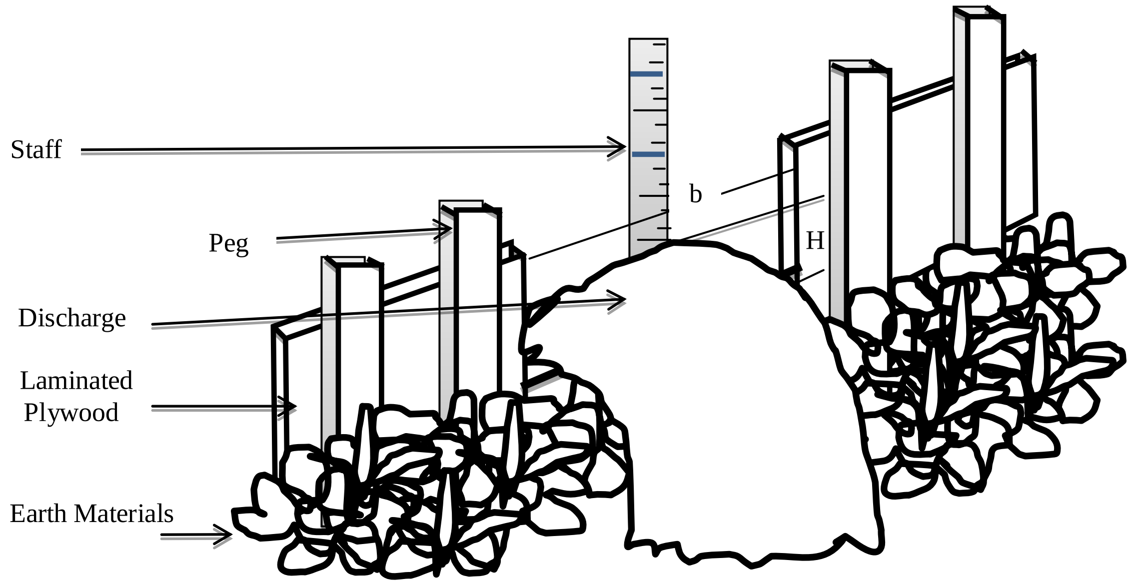


Fig: 2. Rectangular Weir (gauge station) b = weir crest (100 cm) , H = head of water above crest

Reading is done by recording the level of water from the staff immediately the water level becomes same with the weir crest and also when the water is at full discharge. This usually occurs after 4 – 5 minutes of full discharge. Readings are taken at 4th and 6th minute of flow to see if variation exists. The discharge q was computed using weir equation [10]. Weir equation is given according as;

$$q = k\,(b - 0.2H)\,H^{3/2} \qquad \ldots\ldots 2$$

Where;

q = discharge (ls^{-1} or $cm^{3}s^{-1}$)

b = crest width (cm)

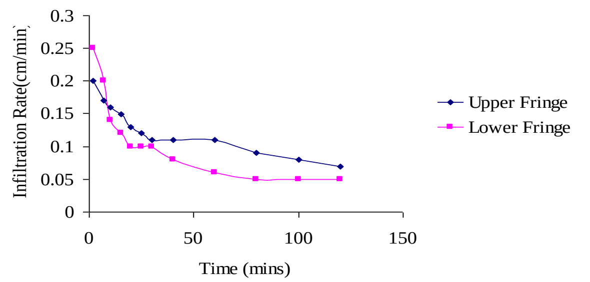
H = head (difference between the crest and the water surface) at a point upstream usually 4 times the maximum head of the crest.

K = unit constant (0.0184 or 184)

IV. RESULTS AND DISCUSSION

A. Infiltration characteristics

Results of experiment conducted by double ring infiltrometer on the field, both at the lower and upper fringes were plotted as given in Fig 3. Infiltration rate decreased faster with time at the upper fringe than the lower fringe. The reason for this is obvious; the lower fringe is bounded by the natural stream channel which serves as drainage channel for water flux from the upland and hence high infiltration rate at the lower fringe.



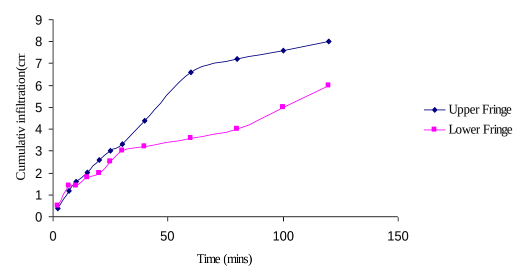


Fig 3. Infiltration and Cumulative infiltration curve for the upper and lower fringes of the inland valley.

B. *Hydraulic Conductivity (Kθ)*

A very low hydraulic conductivity Kθ of 0.04-0.8 and 0.046 – 0.7 for both lower and upper fringe of the field were recorded respectively. When carefully compared with representative physical properties of soil presented by Hansen et al [11]. The soil could be placed in two textural classes of clay loam and sandy loam due to the range of values.

Table 1; Results of the experiment on hydraulic conductivity

		Lower fringe		upper fringe	
L(cm)	t(hr)	θ (cm^3/cm^3)	Kθ	θ (cm^3/cm^3)	Kθ
100	0.0	0.24	-	0.22	-
100	1.0	0.23	0.8	0.21	0.7
100	6.0	0.19	0.5	0.17	0.3
100	24.0	0.17	0.09	0.16	0.06
100	48.0	0.16	0.04	0.15	0.05
100	72.0	0.15	0.03	0.13	0.03

C.. *Soil Physical Properties*

Table 2 below gives the mean values of the soil properties.

D. *Bulk Density (g/cm^3)*

From table 2, rang of bulk density (1.12 and 1.60 g/cm^3) and average dry bulk density with average (1.32g/cm^3) is in conformity with the general standard established by American Society of Soil Science [10].

E. *Porosity (f %)*

An average value of 32.31 % for the porosity as determined fell within the standard range of (30 – 60%); though values outside this range occurred at depth of 90 – 120cm which might be due to structural characteristics of the soil

F. *Particle density*

Mean particle density of 1.48-2.59 was obtained which is below the standard range of 2.6 – 2.7. This is because of the presence of organic matter which lowers particle density.

G. *Available Moisture Content (%)*

From table (2), available moisture content increases with depth up to the crop root zone of 100cm and then decreases to increase further again. This trend also corresponds to that of the moisture content.

Table 2 Mean values of the soil properties

Profile depth	M_c(%)	$\ell_b(g/cm^3)$	$\ell_s(g/cm^3)$	f(%)	AM(%)
0-30	15.62	1.53	1.87	31.94	20.04
30-60	15.64	1.49	1.92	36.45	22.54
60-90	21.02	1.38	2.21	40.12	25.65
90-120	11.25	1.30	1.82	22.64	16.57
120-150	29.33	1.32	2.52	41.37	28.35
150-180	13.40	1.65	1.66	25.11	16.38
180-200	11.42	1.55	2.00	25.62	16.52

I. *Moisture Contents (M_c%)*

The trend of moisture content, porosity and available moisture showed an increase from 0 to 90cm depth with a sharp decrease between 90 to 120cm and increased again from 120 to 150cm and finally decreases at depth lower than 150cm. This explains why the soil is sandy loam at 0 to 30cm, sandy between 90 to 120cm and also clay at 120 to 150cm. The clay loam, at 30 to 90cm and beyond has the tendency of retaining more moisture (fig 6).

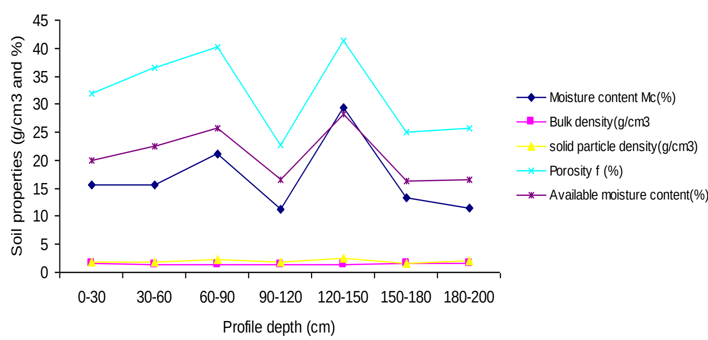


Fig. 4: Moisture content along the soil profile for different locations.

How ever the particle density and the bulk density do not showed significant variation with depth of profile indicating that these properties do not contribute to the type of soil thus do not contribute to recharging the stream channel.

Textural class

The mechanical analysis test by sieving showed that the inland valley has a high percentage of sand at depth of 0cm -30cm and nearly equal percentage of sand, silt and clay between 30cm – 60cm depth. At 60cm – 90cm depth, high percentage of sand was recorded again while the depth of 90cm – 120cm shows very high percentage of clay (Table 3). This is attested by the classification accorded with the findings from the hydraulic conductivity above.

Table 3; Percentage particle size distribution within the experimental field.

Soil Depth (cm)	Avarage Particle Size Distribution				
	Gravel (g)	Soil (g)	%Sand	%Clay	% Silt
0 – 30	74.3	983.3	67.8	15.2	17.0
30 – 60	23.2	134.3	34.4	36.6	29.0
60 – 90	56.2	941.1	50.0	29.2	10.8
90 – 120	18.0	1028.3	11.9	74.1	15.0

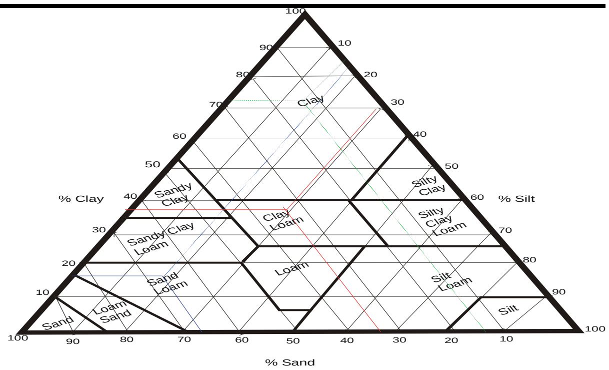


Fig 5 Textural Classification of Soil within the Inland Valley

J. Inland Valley Stream Discharge

It was observed that maximum discharge found (41.897ls^{-1}) occurred in the month of October, while the minimum (0.058ls^{-1}), occurred in the month of July (Table.4).

A plot of the hydrograph to express the trend in discharge and the possible relationship between stream discharge and daily storm depth are presented in figure 4 and 5 respectively. The hydrograph clearly indicates that the rising limb is gradual with respect to the attainment of peak discharge. Also apparently obvious is the multi-peak nature of the hydrograph indicating bimodal rainfall pattern of the inland valley. In addition, the recession limb shows a sudden attenuation or decline. These characteristics seemingly denote the slow nature of the rainfall incident at its inception as noticed in the rising limb of the hydrograph. But upon the attainment of peak, the peaks are closely nested at seeming short intervals; this basically could be attributable to the intermittent nature of the rainfall event, i.e., the time of attainment of a particular peak is not protracted. The sudden attenuation witnessed in the recession period as shown in the hydrograph could be due to sudden stoppage of the rainfall event or probably attributable to physiographic or ambient conditions of the catchments of the Inland Valley.

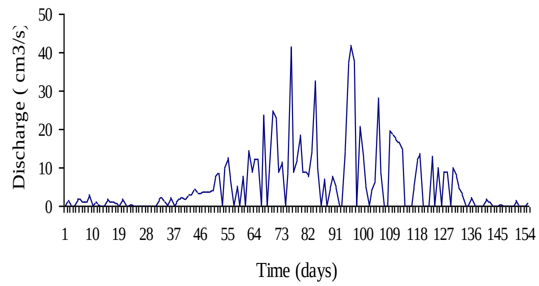


Fig. 4 Stream Channel Discharge Hydrograph

When discharge is compared with storm depth and random run off volumes, it could be seen that low storm depth of 0.1mm indeed translated to minimum runoff, however, it does not translate to minimum discharge but rather 8.937l/s. In contrast, the high storm depth of 41.5mm did not translate to highest runoff and discharge but rather 260l and 41.5l/s respectively (Table 4). Precisely, the peak discharge (41.897l/s) if compared with the storm depth and random runoff volumes occurred on October and its corresponding runoff volume of 270l and storm depth of 2.4mm were not the peak on this day, the discharge rather could be as a result of over saturation of the soil from previous period which may have led to high runoff as infiltration must have subsided. This is antecedent factor in rainfall-runoff relationship [2]

K. Weir Calibration

The stream channel discharge Q was monitored on daily bases from the commencement of discharge in June to the cessation in December. Weir equation was used to compute the actual discharge while the observed discharge was taken by calculating the head of water from flow and the two results were used to calibrate the weir given in table 4.

Table 4. Calibration on weir

Time(s)	Head of water(cm)	Volume of Water collected(l)	Discharge (l/s) Actual	Observed
60	0.5	42.2	0.702	0.650
60	1.0	113..5	1.889	1.836
60	1.5	205.6	3.437	3.370
60	2.0	315.8	5.270	5.188
Mean	1.25	422.4	2.927	6.650

Calculations;

Observed Discharge $= 0.0184(100 - 0.2H)H^{3/2}$

$= 0.0184(100\text{-}0.2\text{x}0.5)0.2^{3/2} = 0.650$ l/s

Actual Discharge = Volume of water collected/60s

= 42.2/60 = 0.702 l/s

Hence relative percentage of observed discharge to actual discharge was calculated as;

$$\frac{ObservedMean}{ActualMean} x100\% = \frac{2.6495}{2.967} x100\% = 94.50\%$$

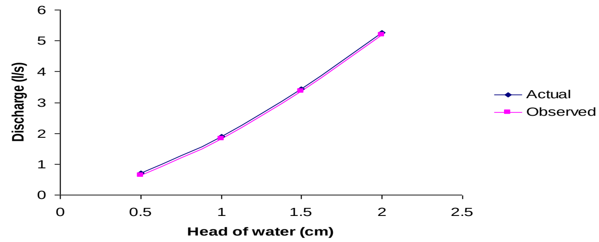


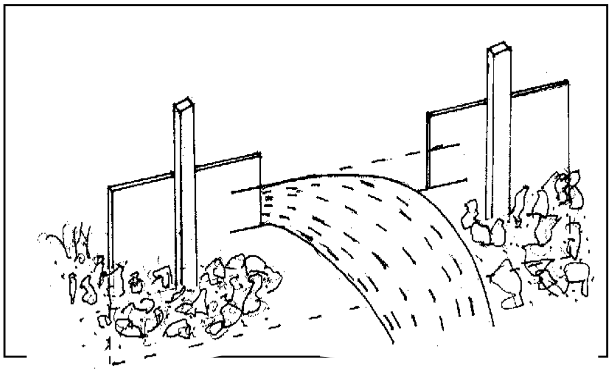
Fig6; Relationship between head of water and discharge

This result implies that the observed discharge is 5.5% lower than the actual discharge.

Table 5: Daily storm depth and inland valley stream discharge.

Months /Days	JUL S.D	JUL I .V.C.D	AUG S.D	AUG I.V.C.D	SEPT S.D	SEPT I. V.C.D	OCT S.D	OCT I,V,C.D	NOV S.D	NOV I.V.C.D
1	-	-	0.3	1.824	-	8.987	3.0	14.586	-	9.848
2	15.0	1.295	0.3	2.360	19.4	12.126	9.5	37.270	-	-
3	-	-	o.o	1.295	1.9	12.126	2.4	41.897	04	8.987
4	-	-	-	-	-	-	4.6	37.270	0.6	8.986
5	TR	1.821	11.2	2.360	21.9	23.793	-	-	-	-
6	9.6	1.814	-	-	1,4	-	17.9	20.595	0.2	9.848
7	1.1	1.295	3.8	1.295	32.0	9.848	11.2	12.590	-	7.722
8	2.5	1.086	1.4	1.821	4.4	24.856	-	5.364	-	4.645
9	3.0	2.963	3.1	2.076	-	22.696	-	-	-	2.963
10	3.5	-	2.1	1.821	0.5	8.9875	-	3.939	-	-
11	-	1.002	5.4	2.962	26.0	11.650	-	6.516	-	-
12	0.7	0.461	8.5	2.962	1.7	-	10.0	28.124	-	2.361
13	0.5	-	-	4.284	-	8.987	22.3	8 987	-	-
14	-	-	-	3.278	.	41.5	11.6	5.0	0.11	9.549
15	-	1.821	12.6	3,278	-	8.987	16.6	-	-	-
16	14.0	1,164	3.3	3.778	1.8	12.126	-	19.549	-	-
17	6.8	1.163	20.2	3.778	TR	18.515	-	18.515	-	1.822
18	0.5	0.611	0.1.	3.858	1.2	8.726		17.499		1.245
19	0.5	0.058	0.1	3.939	1.2	8.937	-	16.483	-	-
20	0.4	1.821	4.7	7.666	0.6	7,666	-	14.507	-	-
21	0.3	-	0.2	8.559	0.1	14.607	-	-	-	-
22	0;3	-	8.6	-	34.0	32.691	-	-	-	0.467
23	0,4	0.461	3.9	9.859	-	9.848	-	-	-	-
24	0.4	-	5.0	12.594	11.5	-	4.0	5.367	-	-
25	6.4	-	8.0	6.910	-	6.910	6.0	12.126	-	-
26	-	0.058	-	-	0.2	-	0.30	13.542	-	-
27	0.1	-	1.7	5.100	-	4.996	-	-	-	0.164
28	-	-	18,8	-	17.6	7.722	-	-	-	
29	-	0.163	27.8	7.771	0.9	4.996	-	-		-
30	6.3	-	4.7	-	-	-	-	13.066	-	-
31	-	-	-	14.58	-	-	0.3	-	-	0.164

IVCD=Inland Valley Channel Discharge cm3/s **SD=Storm Depth cm**



L. Storm depth and stream channel discharge:

The plot of total daily rainfall against mean daily discharge shows the same trend of increase from June to September or October (Fig. 5.0) as the case may be and decline from there to November and December. It is glaringly evident that there is close linearity between these variables as what is obtainable is somewhat linear. The linearity is more affected at the lower storm and also discharges than higher points. The physical implication of this is that the storm event does not translate directly in totality to stream discharge, some (32.3%) were intercepted by vegetations, collected as surface water, and depreciated to become groundwater. Surface water (runoff) and groundwater moves laterally or by gravity to recharge streams at full saturation of soils. [2]

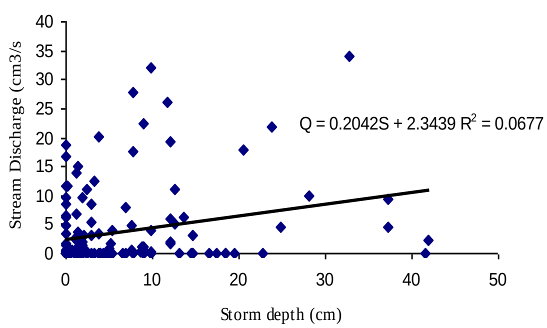


Fig 8. Storm depth/Stream Channel Linear seperation

V. CONCLUSSION

Findings from this research has showed that the sandy loam type of soil underplayed by clay loam does not facilitate uniform flux of groundwater to the stream channel, however despite the interception of vegetation , about 76% of storm water discharges to the stream channel . At the unset of rain most of the storm goes to saturate the soil up to the month of August as highest rain in October culminate highest channel discharge in October. There was zero or no discharge between December ant March, hence farming activities can only be possible with irrigation by construction of dams or tube wells otherwise cropping intensity will be restricted to once.

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