RAINFALL-RUNOFF RELATIONSHIP FOR DIFFERENT DEGREE AND LENGTH OF SLOPES IN SMALL CATCHMENTS

S.K.Nalatwadmath, M.S.Ramama Mohan Rao, S.Chittaranjan,
N.S.Jayaram, R.N.Adhikari, and V.Husenappa.
Central Soil and Water Conservation Research and Training Institute,
Research Centre, Bellary – 583 104, Karnataka

ABSTRACT

A study on runoff and soil loss was conducted (1986-99) to study the effect of rainfall, degree and length of slope in vertisols of Bellary (Karnataka) on runoff, soil loss and to determine optimum length of runoff plots. Runoff and soil losses as influenced by rainfall, degree and length of slopes were assessed from plots of four lengths i.e., 22.13, 44.26, 66.39 and 88.52 m having uniform width of 1.83 m at three slopes nameiy 0.5%, 1.0% and 2.0%. The smallest length (22.13m) has produced maximum runoff and soil loss. As the length of the slope increases runoff percentage as well as soil loss per unit area have decreased considerably. Runoff and soil loss increased with increased slope of percentage. The runoff percentage and soil loss were found to be negatively correlated with length while it was positively correlated and linear with degree of slope. The runoff and soil losses were higher up to 50m length and thereafter the runoff and soil losses were almost constant in all the slope groups. Thus optimum length of runoff plot was found to be 50m. Analysis of hydrographs obtained during 1998 and 1999 have indicated that there is a low peak and less volume in case of 66.39 m plot in comparison to 22.13m plot for all three slopes. The rising time or time to peak from initiation of runoff is less in the case of shorter length than longer lengths. It may be attributed to less time of concentration and opportunity time for infiltration with plots of shorter length when compared to longer runoff plots. This may be useful in planning and designing urban drainage system which usually having small catchments.

1.0 INTRODUCTION

Rainfall is not uniformly distributed with respect to time or location. This characteristic has brought about attempts to manage water resources to minimize floods during the wet seasons or store the water for later use during dry seasons, or both. The use of water has been important to the economic development of areas. People in the semi-arid region are aware that water is either presently or rapidly becoming a scarce resource. Black soils (vertisols and associated soils) occupy about 73 m ha and are mostly confined to the semi-arid areas of the central plateau of India (Murthy, 1988). Vertisols form nearly 80% of the total area of north karnataka. These soils are clay, with poor structure, low infiltration, highly erodeble, alkaline in reaction and cracking heavily on drying. They remain devoid of vegetative cover during most part of the year. These soils have a rolling topography with mild slopes (0.5-2%) extending over long lengths

(1-3m). As a result of these, soil losses to the extent of 12 to 43 tonnes/ha/year are common for unprotected lands (Chittaranjan et al. 1980). Low infiltration rate (<1mm/hr), Poor structure due to low organic matter, renders them highly erodible with K (erodibility factor) value ranging from 0.3 to 0.6 (Rama Mohan Rao and shshachalam, 1976). Such an alarming rate of soil erosion has affected the productivity of the existing land and creating problems of drainage in the region.

For sound soil and water conservation reliable soil loss estimation is a valuable tool in designing planning and execution. It's most immediate advantage is that a well defined conservation objective can be formulated to reduce soil losses to specified acceptable levels and thereby ensure the maximum safe use of land and water.

2.0 MATERIAL AND METHODS

The experiment was carried for 13 years, 1986 to 1999, (except during 1997, there was very low rainfall) at the Central soil and Water Conservation Research and Training Institute, Research Centre, Bellary. Runoff and Soil losses were assessed from plots of four lengths i.e.22.13, 44.28, 66.39 and 88.52m having uniform width of 1.83 m at three slopes namely 0.5%, 1.0% and 2.0%. Runoff plots were equipped with multislot devisors with runoff collecting tanks for measurement of runoff and soil loss. During 1997-98, stage level recorders were installed in different plot to measure the peak rate of runoff. (All the plots were maintained as cultivated fallow). The soil belong to Bellary series and are pellusterts (Vertisols). Soil is deep with clayey texture containing 44.6% clay, 13.4% silt and 21.3% sand. The annual rainfall, no. of rainy days, runoff causing rainfall and no.of runoff causing events are given in Table-1. Hydrographs and runoff samples were collected every day at 8.30 hrs for estimating sediment and runoff.

Table 1 : Annual rainfall, no.of rainy days, runoff causing rainfall and no.of runoff causing events

Year	Annual rainfall (mm)	No. of rainy days	Runoff causing rainfall (mm)	No. of runoff causing events
1986	447.0	32	273.8	8
1987	431.3	31	161.0	5
1988	579.2	36	307.4	8
1989	522.9	31	310.2	8
1990	451.2	28	308.2	11
1991	473.2	25	295.4	6
1992	888.7	28	557.1	16
1993	477.9	39	261.3	12
1994	383.6	31	196.4	9
1995	383.5	28	187.4	9
1996	840.8	40	632.5	15
1997	221.0	20	59.4	2
1998	622.4	33	447.1	16
1999	522.4	25	394.9	12
Mean	517.5	30.5	313.8	9.8

The poled data was subjected to regression analysis (Panse and sukhatme, 1981) and regression equations were derived. Analysis of hydrographs was carried out from all the plots.

3.0 RESULTS AND DISCUSSION

Slope length

The runoff and soil loss data recorded during thirteen years 1986 to 1999 was pooled and the average runoff and soil loss are given in table 2. Maximum runoff (192.4mm) and soil loss (8.10 t/ha) occurred under 22.13 m plot length with 2.0% slope. Across slopes, 22.13 m plot length produced maximum runoff (174.4mm) and soil loss (6.75 t/ha). Runoff and soil loss decreased progressively with minimum value of 111.0 mm runoff and 3.65 t/ha soil loss under 88.52m plot length. The progressive decrease in runoff and soil loss with increase in slope is attributed to the very mild slope which did not allow water to move with erosive velocity thereby not causing appreciable soil loss (Ratan Singh et al. 1997). The stream transport to heavier particles for shorter length is comparatively more than the longer lengths. Pot hole formation due to deep and wide craks in the soil is another reason as considerable quantities of water and soil loss get trapped into it, as the soils under study are vertisols with montmorillonitc type of clay minerals. Similar results were also reported by Singh and Katiyar (1995) in vertisols of KOTA (Rajastan).

Table 2 : Effect of steepness and length of slope on runoff and soil loss (Average of 13 years)

Length	Runoff (mm)				Soil loss (T/ha)			
	0.5%	1.0%	2.0%	Mean	0.5%	1.0%	2.0%	Mean
L1 (22.3)	155.8	175.1	192.4	174.4	5.38	6.78	8.10	6.75
L2(44.26)	108.9	134.2	163.0	135.4	3.13	4.35	6.46	4.65
L3(66.39)	103.1	144.4	138.5	118.7	3.34	3.76	6.82	4.64
L4(88.52)	091.4	110.3	131.4	111.0	2.82	3.35	4.78	3.65
Mean	114.8	113.5	156.3		3.67	4.56	6.54	

The runoff and soil loss data recorded during thirteen years was pooled and the average runoff (% of runoff causing rainfall) and soil loss (kg/ha/mm) were worked out and are given in Table-3. The results indicated that the smallest length has produced maximum runoff and soil loss. As the length of the slope increase, runoff percentage as well as soil loss per unit area have decreased considerably. This behavior of the local vertisols has been found to be in confirmity with that of vertosols of Kota, Rajastan (Singh and Katiyar, 1995) and black clays of Hustan, USA (Baver, et al. 1978), probably due to trap efficiency as the length increased. This could be attributed to the parameters such as flow velocity, stream transport of heavier particles for shorter lengths, pothole formation and related factors as indicated earlier. It is also commonly observed that the runoff and soil loss per unit area from smaller catchments is always more than the bigger catchments.

The runoff and soil losses are higher upto 50 m length and thereafter runoff and soil losses are almost constant in all the slope groups. This indicates that the cut off length is 50 m for implementing any soil conservation measures in the black soils of Bellary. Thus optimum length of runoff plot was found to be 50 m.

Table 3 : Runoff (% of runoff causing rains) and soil loss (kg/ha/mm) - average of 13 years (1986-1999)

Length (m)	Runoff (% of runoff causing rainfall)			Soil loss(kg/ha/mm)		
	0.5%	1%	2%	0.5%	1%	2%
L1(22.13)	44.67	50.27	56.74	23.2	27.1	29.9
L2(44.26)	30.15	37.11	45.51	11.3	14.3	20.2
L3(66.39)	29.69	33.29	39.46	13.1	13.4	16.0
L4(88.52)	28.04	31.25	37.44	10.0	12.9	15.7

The pooled data recorded over thirteen years has been subjected to regression analysis. The relationship between length of slope and runoff percentage and soil loss have been worked out and the same are given below along with 'r' values.

$Y=79.53-27.45 \log X (r = -0.94)$ for 0.5%
$Y=92.13-32.04 \log X (r = -0.98)$ for 1.0%
$Y=100.00-33.00 \log X (r = -0.99)$ for 2.0%

Where X is slope length in meters and Y is run off%.

$Y=49.17-20.56 \log X (r = -0.89)$ for 0.5%
$Y=57.36-23.93 \log X (r = -0.92)$ for 1.0%
$Y=62.00-24.68 \log X (r = -0.97)$ for 2.0%

Where X is slope length and y is soil loss in kg/ha/mm.

The runoff percentage and soil loss were found to be negatively correlated with the length of plot.

Slope gradient

Runoff and soil loss increased with increased slope gradient (Table-2). Maximum runoff (192.4mm) and soil loss (8.10 t/ha) occurred under 2.% slope with 22.13 m slope length. Minimum runoff (91.4mm) and soil loss (2.82 t/ha) was observed under 0.5% slope with 88.52m slope length. Across slope lengths, 2.0% slope produced maximum runoff (156.3mm) and soil loss (6.54 t/ha). Minimum runoff (114.8 mm) and soil loss (3.67 t/ha) was observed with 0.5% slope. Runoff and soil loss values increased progressively as the slope percentage increased. This is in conformity with the findings of Walter et al. (1978). Similar trends were observed with runoff percentage and soil loss per unit area (Table-3).

The relationship between degree of slope and runoff percentage and soil loss were worked out and the same are presented below along with 'r' values.

$Y=41.44+7.82X$ ($r = 0.99$) for L1
$Y=25.95+9.98X$ ($r = 0.99$) for L2
$Y=25.95+9.98X$ ($r = 1.00$) for L3
$Y=24.95 +6.26X$ ($r = 1.00$) for L4

Where X is degree of slope and Y is runoff % and

$Y=21.81+4.21X$ ($r = 0.96$) for L1
$Y=08.40+5.90X$ ($r = 1.00$) for L2
$Y=11.81+2.01x$ ($r = 0.97$) for L3
$Y=08.59+3.68X$ ($r = 0.98$) for L4

Where X is the degree of slope and Y is soil loss (Kg/ha/mm).

The runoff percentage and soil loss per unit area are positively and linearly correlated with steepness of slope.

3.1 Analysis of Hydrographs from Longer Runoff Plots

Four typical hydrographs observed on 25.9.98, 30.9.98, 14.5.99 and 17.10.99 are presented in Fig. 1,2,3 and 4. Hydrographs from the plots having lengths of 22.13 and 66.39 m under 3 different slopes ie.,0.5%, 1.0% and 2.0% are presented in Fig.1,2,3 and 4. In all the four situations runoff trend is same.

Table 4 :.Characteristics of the hydrograph observed for rain fall on 25.9.98

Slope (%)	Treatment Length (m)	Area (m^2)	Rainfall (mm)	I_{15} (mm/hr)	API	Runoff (mm)	Rising time (minutes)
0.5	L1(22.13)	40.5	20	48	26.7	5.20	12
1	L1	40.5	20	48	26.7	7.11	10
2	L1	40.5	20	48	26.7	7.53	5
0.5	L3(66.39)	121.5	20	48	26.7	4.91	10
1	L3	121.5	20	48	26.7	4.95	9
2	L3	121.5	20	48	26.7	6.70	8

Table 5. : Characteristics of the hydrograph observed for the rainfall on 30.9.98

Slope (%)	Treatment Length (m)	Area (m^2)	Rainfall (mm)	I_{15} (mm/hr)	API	Runoff (mm)	Rising time (minutes)
0.5	L1(22.13)	40.5	40.2	86	35.8	25.67	6
1	L1	40.5	40.2	86	35.8	26.39	6
2	L1	40.5	40.2	86	35.8	30.76	5
0.5	L3(66.39)	121.5	40.2	86	35.8	19.16	10
1	L3	121.5	40.2	86	38.8	21.27	10
2	L3	121.5	40.2	86	38.8	29.12	10

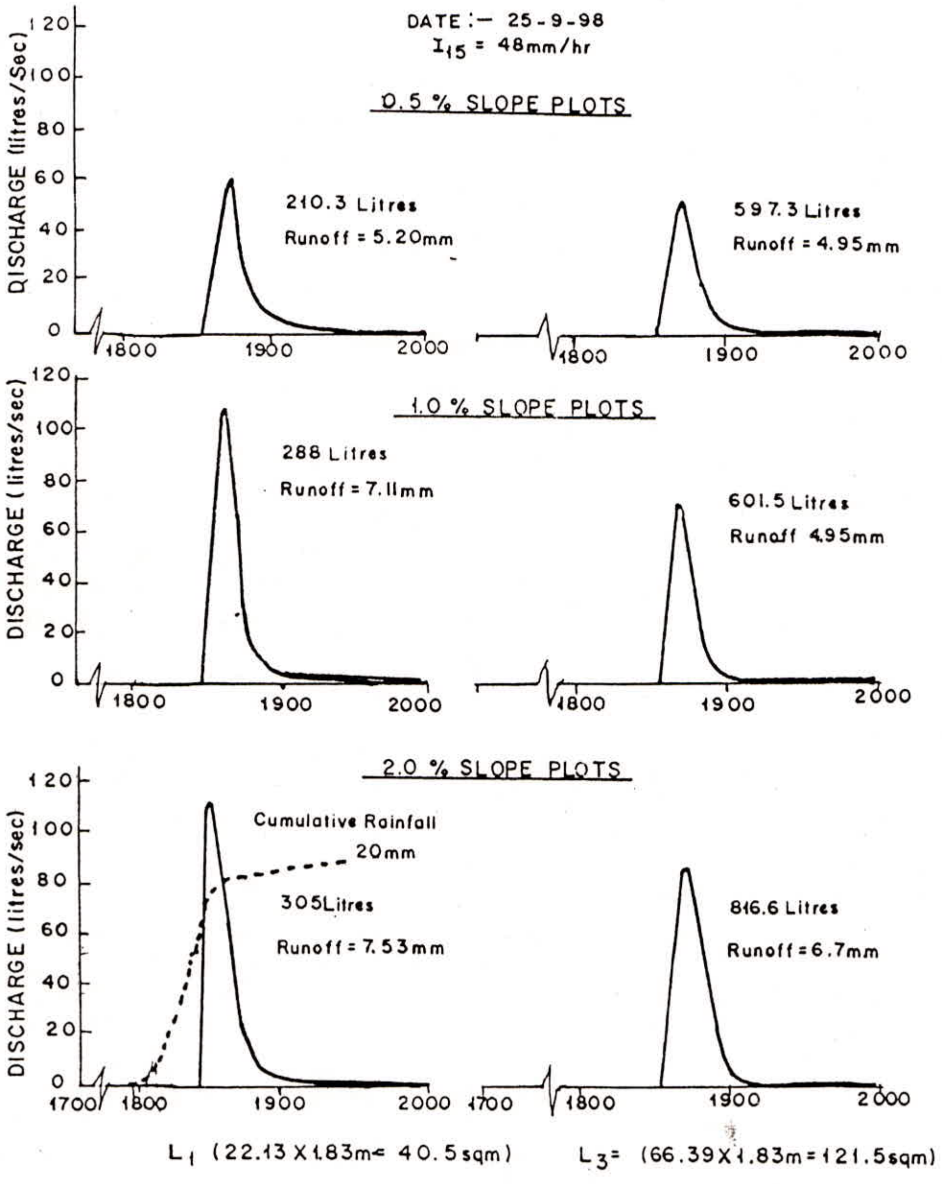

Fig. 1 : Characteristics of Hydrograph in Length and Slop Experiment

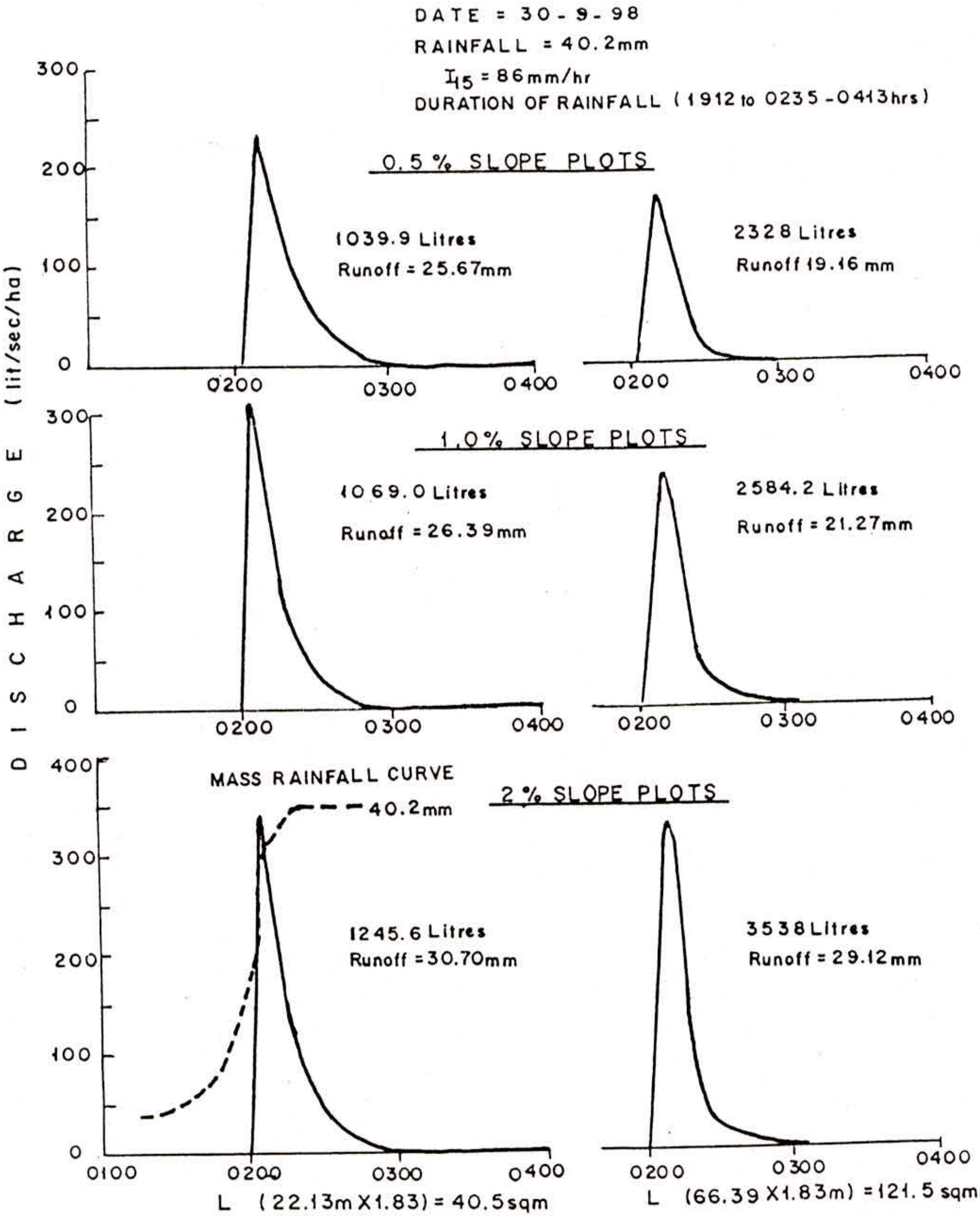

Fig. 2 : Characteristics of Hydrograph in Length and Slope Experiment

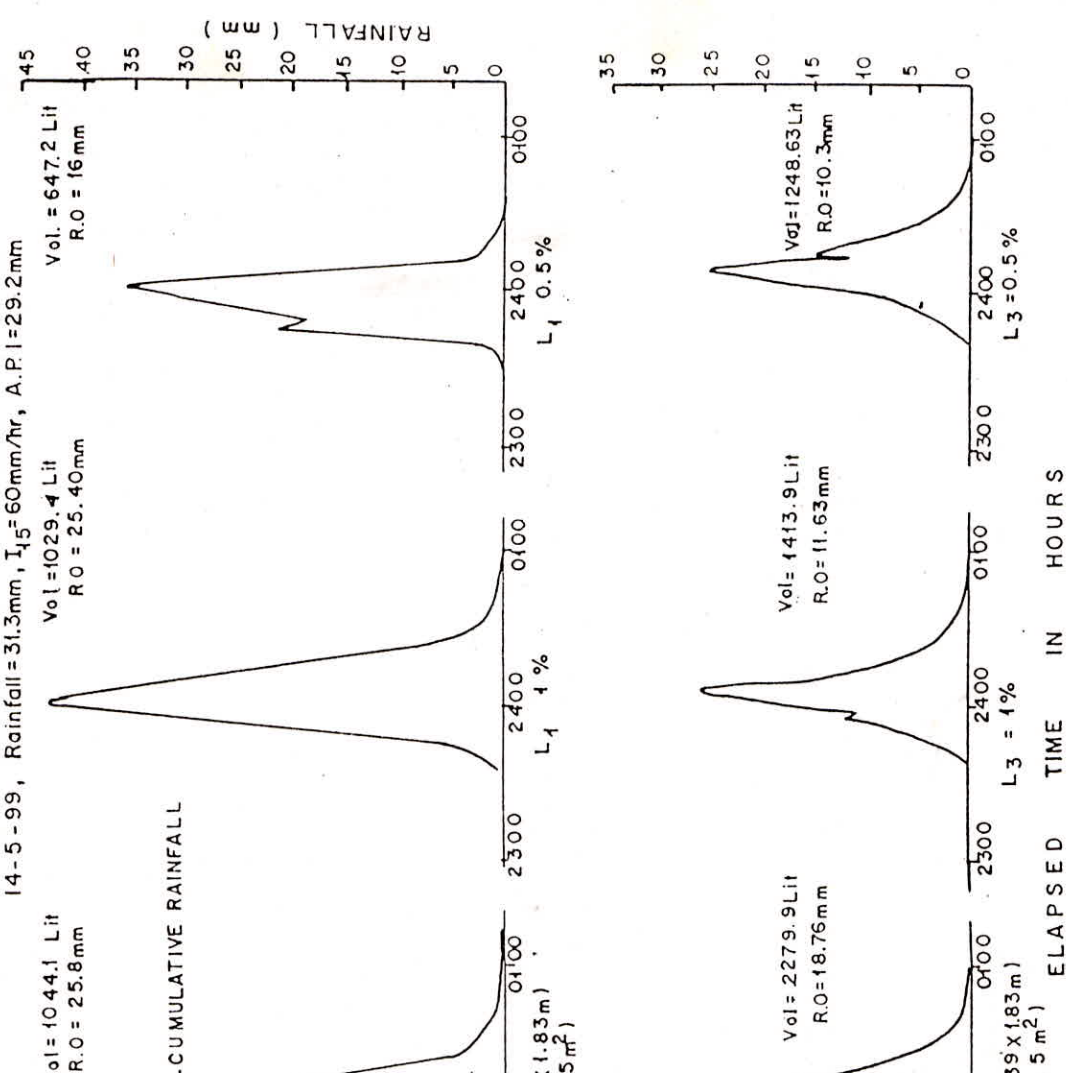

Fig. 3 : Characteristics of Hydrograph in length and slope experiment

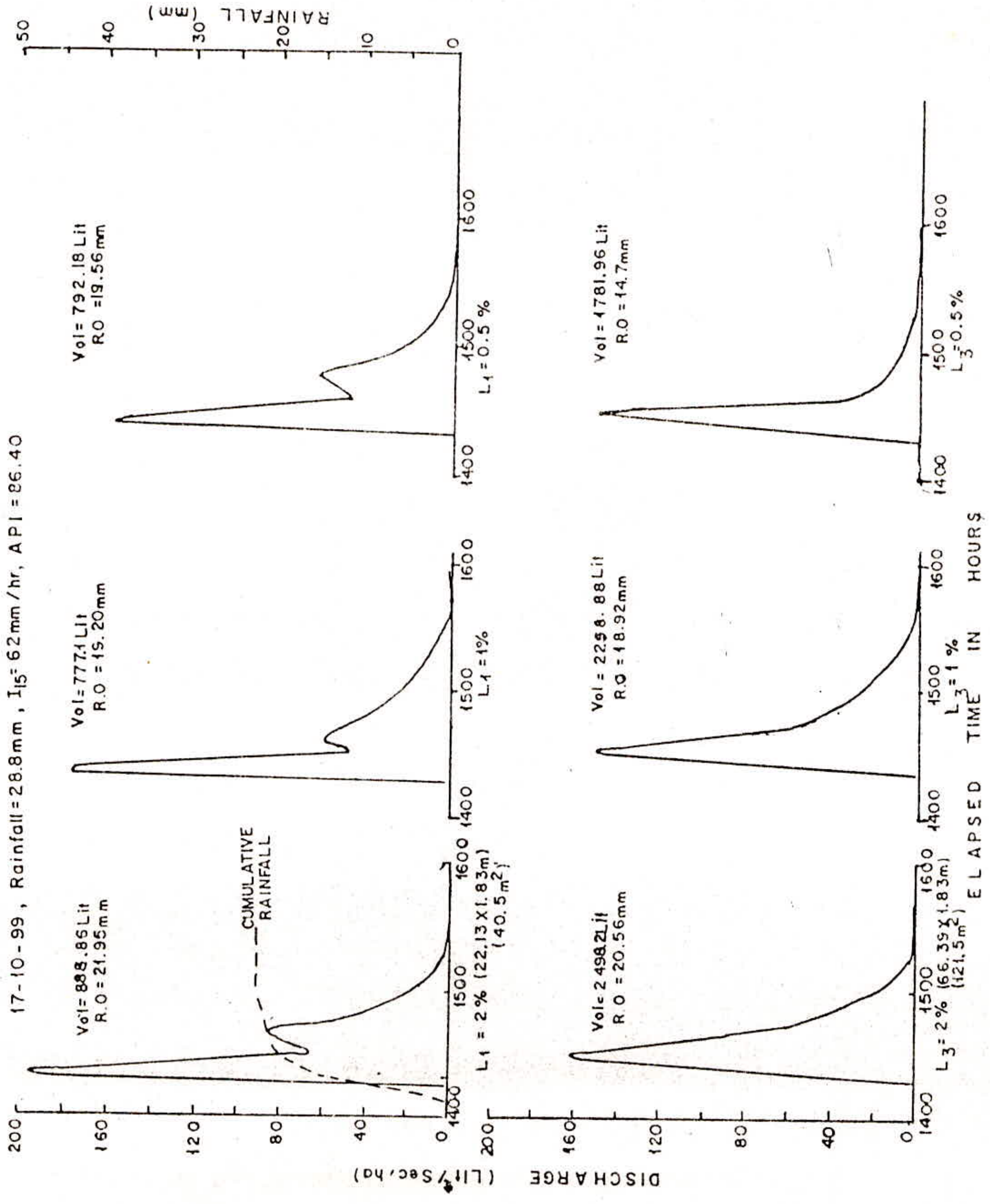

Fig. 4 : Characteristics of Hydrograph in Length and slope experiment

Table 6. : Characteristics of the hydrograph observed for the rainfall on 14.5.99

Slope (%)	Length (m)	Area (m^2)	Rainfall (mm)	I_{15} (mm/hr)	API	Runoff (mm)	Rising time (minutes)
0.5	L1(22.13)	40.5	31.3	60.0	29.2	15.97	26
1	L1	40.5	31.3	60.0	29.2	25.40	26
2	L1	40.5	31.3	60.0	29.2	25.50	23
0.5	L3(66.39)	121.5	31.3	60.0	29.2	10.28	28
1	L3	121.5	31.3	60.0	29.2	11.63	27
2	L3	121.5	31.3	60.0	29.2	20.32	27

Table 7 : Characteristics of the hydrograph observed for the rainfall on 17.10.99

Slope (%)	Length (m)	Area (m^2)	Rainfall (mm)	I_{15} (mm/hr)	API	Runoff (mm)	Rising time (minutes)
0.5	L1(22.13)	40.5	28.8	62.0	86.4	19.50	6
1	L1	40.5	28.8	62.0	86.4	19.70	6
2	L1	40.5	28.8	62.0	86.4	21.95	5
0.5	L3(66.39)	121.5	28.8	62.0	86.4	14.7	13
1	L3	121.5	28.8	62.0	86.4	20.6	12
2	L3	121.5	40.2	62.0	38.8	29.12	12

It is observed from the table 4,5,6 & 7 as well as from the figures 1,2,3 and 4 that there is a low peak and less valume in the case of 66.39 m plot in comparison to 22.13 m plot for all the three slopes. It is also observed that the rising time or time to peak from initiation of runoff is less in the case of shorter length than longer lengths. The reason may be attributed to less time of concentration and opportunity time for infiltration with plots of shorter length when compared to longer runoff plots. This may be useful in planning and designing urban drainage system, which usually having small catchments.

REFERENCES

Baver, LD., Gardner, W.H. and Gardner, R.V.(1978). Soil Physics, Indain Reprint, wiley, Eastern ltd., New Delhi.

Chittaranjan, S.Ramanath, B. and Rama Mohan Rao, M.S (1980). "Mechanical structures for soil conservation and deep black soils" Extension Bulletin No.1, CWWCRTI, Research Centre, Bellary.

Murthy, A.S.P.(1988). Distribution, properties and management of vertisols of India. Advances of soil Science. Vol.8, PP.151-214.

Panse, V.G. and Sukhatme, P.V.(1961). Statistical method for agricultural workers, ICAR, New Delhi.

Rama Mohan Rao,M.S. and Seshachalam, N.(1976). Improvement of intake rates in problem black soils. Mysore Journal of Agricultural Science, Vol.10, PP.52-58.

Ratan Singh, Prasad, S.N. Singh, K.D. and Samra, J.S.(1979). Runoff soil and nutrient losses in vertisols of south Eastern Rajastan. ICAR Bulletin No.T-34/K-4, CSWCRTI, Research Centre, Kota.

Singh, R. and Katiyar, V.S.1995. To work out parameters of universal soil loss equation and to study the erodibility of Kota clay soils. Annual Report (1994-95), CSWCRTI, Research Centre, Kota.

Walter, H. Wischmeir, W.H. and Smith, DD. 1978. Predicting rainfall erosion losses – a guide to conservation planning. USDA Agricultural hand Book No.537.