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Estimation of curve numbers for different soil conservation measures in lateritic soil of south Konkan region

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ABSTRACT

Seven years (1992-1998) rainfall data of Agricultural Research Station, Mulde, District Sindhudurge in South Konkan of Maharashtra State was analyzed for every storm to determine storm wise AMC condition. The entire events, fall in each AMC I, II, III were grouped in small, medium and large class. The potential retention (S), value for different storm group with different AMC was then computed by using lognormal distribution for runoff and rainfall pair data. This potential retention value was used for the computation of CN for given condition of the watershed. The estimated average CNs for different conservation measures for AMC I, II, III are 77.93, 81.31 and 84.57, respectively. The VGB produces more runoff followed by NCM, ST and RT. The standard error was also higher in case of NCM (36.28%), which was then followed by VGB (30.64%), PT (20.65%) and other micro watershed (1.68 to 19%). The mean percent runoff factors observed were 45.70, 23.99, 24.45, 23.55, 26.32 and 50.27 for NCM, IBT, ST, PT, RT and VGB, respectively. The intermittent bench terracing (IBT) and platform terraces (PT) were found more effective in controlling the runoff to other conservation measures. The observed and computed runoff from study area was found non significant at 5% level of confidence. Hence, Computed CNs can be used for estimation of runoff from an ungauged watershed.

1. INTRODUCTION

The design of rainwater harvesting structures are essentially depends on runoff potential of the watershed. Runoff potential is a surface phenomenon that varies from storm to storm and represents the overall hydrological response of land surface to the given rainfall event. The estimation of runoff, especially from ungauged watershed is one of major activities in the applied hydrology. Such estimation is needed for design of engineering structures in the post event appraisal work for evaluation of various land use practices and for assessment of environmental impact of watershed development Hawkins (1985, 1993) and Rao *et al.* (2002). Sherman (1942, 1949) on plotting direct runoff Vs storm rainfall, the subsequent work of Mockus (1949), Chunale *et al.* (1999) and King and Balogh (2008) on estimation of surface runoff for ungauged watershed using information on soil, land use, antecedent rainfall, storm duration, average annual temperature. Andrews (1954) developed a graphical procedure for estimating runoff from rainfall for combinations of soil texture and type, amount of vegetation cover and conservation practices. All combined in soil-cover complex or soil-vegetation-land use (SVL) complex (Miller and Cronshey, 1989). Thus, the empirical rainfall-runoff relation of Mockus (1949) and the SVL complex of Andrews (1954) constituted the building blocks of the SCS-CN method. Mishra *et al*. (2008) and Amutha and Prophevlan (2009) compared the different methods for estimation of runoff rainfall relation with SCS-CN methods. Hawkins *et al*. (2009) have summarized the origin, development, role, application and current status of the CN method. Also stated that there is a need to develop locally defined CN values to address concerns with regional and seasonal variations. A good number of models are available for predictions of runoff are location specific such as a stochastic rainfall model, an infiltration model, and an effective rainfall-runoff model for deriving CNs (Kurothe *et al.*, 2001) and provide sufficient information on the complex rainfall runoff process of a watershed system. South Konkan is characterized with its unique biodiversity, high intensity rainfall and flash flood, slope ranging from 7 to 35%. The average annual rainfall of station is 3283 mm distributed over 108 rainy days during the June to October months. There were insufficient gauging station of hydrologic data network and watershed. This region is a coastal belts fall under the restricted zone to share all kind of information as per Govt. regulation. Due to this, such information is lacking in the coastal region of Konkan region in Maharashtra State. Therefore, an attempt was made to develop runoff rainfall relationship for selected CNs for different soil conservation measures.

2. MATERIALS AND METHODS

Study Area

The experiment was conducted at Agricultural Research Station, Mulde, Dist Sindhudurge from 1992 to 1998 to measures the runoff from micro watersheds treated with different conservation measures (Intermittent Bench Terraces (IBT), Staggered Trenching (ST), Platform Terraces (PT), Ring Terraces (RT), Vetiver Grass Bund (VGB) and no conservation measures (NCM)). The details of treatments were imposed as given in Table 1. The plot size of each treatment was 24 m x 40 m (width and length) with an average slope of 15 per cent. The runoff data was available for period of 1992 to 1994 only but rainfall data of 1992 to 1998 (Seven years) available. For comparison of computed runoff only three years data make available. The runoff from different plots were collected by installing the stage level recorder and daily rainfall data of automated rain gauge were collected from Agro Meteorology Station, ARS, Mulde.

Soil Hydrologic Group

The hydrologic soil groups of soil of study area were estimated by adopting the standard procedure (Table 2). Hydrologic properties such as field capacity and wilting point were estimated by pressure plate apparatus, Infiltration measured by using double ring infiltrometer, depth of soil determine by taking actual profile at each plots and permeability measured in laboratory by falling head method. These parameters indicate a soil runoff potential an qualitative basis to decide the soil hydrologic group.

SCS-Curve Number Method

Storms were classified under various Antecedent Moisture Conditions (AMC) for the growing and dormant seasons for the duration 1992 to 1998 from rainfall data as

Table 1:
Details of treatments under study

Sl.No	Conservation Measures	Specifications	Size
1	No Conservation Measure (NCM)	Land Slope was 15 per cent and keep follow Cashew through out treatment.variety Vengurla-4 planted at spacing 8 m x 8m along the slope.	24 m x 40 m
2	Intermittent Bench Terracing (IBT)	Terraces size 4 m length and 1.5 m width were prepared along the contour with 0.3 m depth of cut at the top .	24 m x 40 m
3	Staggered Trenching (ST)	Trenches length 4.5 m, top and bottom width 0.6m, and depth 0.30m were prepared in a staggered manner. One trenched on upper side at VI of 0.6m between two trenched of downward side.	24 m x 40 m
4	Platform Terrace (PT)	The individual terrace of 3.0m length, 3.0 m top width and 3.0 m bottom width was prepared along the contour with 0.3m cut depth at top portion of terrace and excavated soil was spread around square terrace to form a platform.	24 m x 40 m
5	Ring Terracing (RT)	The ring terraces of 4 m radius prepared across the slope along the contour of 4m width and cut depth kept as per site location to make uniform depth.	24 m x 40 m
6	Vetiver Grass Bund (VGB)	A strip of Vetiver grass strips was planted in double row through the aligned contour exactly between two consecutive plant rows across the land slope to check the soil erosion.	24 m x 40 m

Table: 2
Hydrologic-soil groups for different soil conservation measures (soil type sandy loam)

Conservation measures	Soil Depth (mm)	Field capacity, % point,	Permanent wilting %	Infiltration rate (mm hr^{-1})	Permeability (mm hr^{-1})	Hydrologic soil group
NCM	150-300	31.6	18.20	56.0	Moderate to High	HSG-A
IBT	300-450	28.98	18.60	67.0	Moderate to High	HSG-A
ST	300-450	30.43	19.56	68.0	Moderate to High	HSG-A
PT	300-450	29.69	17.99	67.0	Moderate to High	HSG-A
RT	150-450	30.65	18.68	48.0	Moderate to High	HSG-A
VGB	300-450	29.44	18.90	57.0	Moderate to High	HSG-A
Average	250-450	30.16	18.65	60.65	Moderate to High	HSG-A

suggested by SCS 1957 are listed in Table 3. The Curve numbers were calculated for different soil conservation measures *viz.* IBT, ST, PT, RT, VGB, NCB by using the observed rainfall and runoff data by adopting the methodology suggested by Soil Conservation Services (1957). The algebraic and hydrologic relation between storm rainfall, soil site storage and storm runoff is given by following relationship:

$$Q = \frac{(P-I_a)^2}{(P-I_a+S)} \quad .....1$$

Where, P = storm rainfall, mm; Q = direct runoff, mm, I_a = initial abstraction, mm; and S = potential maximum retention, mm.

Initial abstraction (Ia) is estimated from empirical relation based on SCS, (1970).

I_a = 0.1S (For AMC-II and AMC-III of Black soil region) …. 2(a)

I_a = 0.3 S (For AMC-I of Black soil region) …. 2(b)

I_a = 0.3S (For all other soils region and all AMC classes) …. 2(c)

By substituting equation 2(c) in equation 1, we get

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \text{ for Ia} = 0.3S \quad .... 3$$

The following relationship was used for converting selected optimum S value to respective Curve Number (CN).

$$CN = \frac{25400}{(254+S)} \quad ....4$$

Lognormal Method to Determine CNs

Hauser and Jones (1991) developed the procedure to incorporate the lognormal probability distribution of 'S' to determine the CN for three AMC classes, This procedure illustrated by Yoo *et al*. (1993) was adopted and presented below:

1. Computed the S value for each storm event from P and Q data pairs using the following equation:

$$S = 5P + 10\,Q - 10\sqrt{Q2+1.25PQ\,S}, \text{ for } I_a = 0.2S \quad .....5$$

$$S = 3.33P + 3.89\,Q - 3.89\sqrt{Q2+2.45PQ} \text{ for } I^a = 0.3S ...6$$

2. Arranged the calculated S values in descending order (Largest first).
3. Computed the probability of S by the Weibul's formula (Chow *et al.*, 1958)
4. Fit the lognormal probability distribution to S
5. Compute S value and the associated CN at probability = 0.5 which represents AMC-II because the mean logarithm of S corresponds to median of 'S'.

This produces CN values that are essentially identical with those derived by SCS method to avoid the deviation in runoff, instead of S value at P = 0.1 and P = 0.9 for AMCI and AMCIII, respectively. The events of each AMC class under each storm size are applied for lognormal distribution and for each AMC class S value was taken at Probability = 0.5. S value at P = 0.5 represents AMC-II because the mean logarithm of S corresponds to median of S (Hauser and Jones, 1996).

The estimated curve number by using lognormal distribution method and selected table curve number (table value) were compared for different conservation measures by determining runoff for rainfall depths as suggested by Singh *et al*. (1999) and Chunale *et al*. (2001).

Statistical Performance of Estimated Runoff

The statistical performance of estimated runoff using lognormal method and observed runoff were evaluated using student t- test, regression co-efficient (R^2) and root mean square error (RMSE).

3. RESULTS AND DISCUSSION

Hydrologic Properties

The hydrologic properties of soil under different conservation measures such as IBT, ST, PT, RT, VGB and NCM are given in Table 2. The soil is sandy loam with moderate to deep in depth having high infiltration and permeability for all measures. The average field capacity and permanent wiling point of soil under different conservation measures was 30.16 and 18.65%, respectively. The average infiltration capacity of the soil was 60.5 mm/ hr. The soil comes under hydrologic soil group-A.

AMC and Runoff Causing Events Analysis

The maximum 301 runoff events were observed in treatment NCM whereas in other conservation measures ((IBT, ST, PT, RT, VGB) the numbers of events varied from 282 to 297 (Table 3). This variation in runoff events in different measures may be due to watershed characteristics, effect of antecedent rainfall condition, associated soil moisture (Ponce and Hawkins, 1996) and conservation measure adopted. The most of storm groups were observed in the AMC III condition followed by AMC-I. Least runoff-causing events were observed under AMC II condition. Hence, chances of occurrence of runoff under AMC-III naturally are high.

Curve Number by Log Normal Methods

Individual rainfall runoff events recorded in all conservation measures were now classified into three groups as small, medium and large storm depending on their relative storm size suggested by Hawkins (1993) and Chunale (1997) (Table 4). All events within each storm groups were again reclassified into sub group as per their AMC I, II and III. From Lognormal distributions the S value is selected for 10, 50 and 90% probability which represents potential maximum retention for AMC I, II and III, respectively. The CNs from Lognormal distribution method has higher value (94.32 to 77.32) for large group of storm in all AMC Conditions and followed to Small and Medium

Table: 3
Number of runoff events according to storm size under different antecedent moisture conditions

AMC	Storm group	NCM	IBT	ST	PT	RT	VGB
I	Small	22	21	26	22	22	22
	Medium	1	1	1	1	1	1
	Large	1	1	1	1	1	1
Total		24	24	28	24	24	24
II	Small	25	23	25	21	23	19
	Medium	1	1	1	1	0	1
	Large	0	0	0	0	0	0
Total		26	24	26	22	23	20
III	Small	168	159	161	164	160	157
	Medium	55	49	56	55	54	54
	Large	28	28	26	27	28	27
Total		251	236	243	246	242	238
Overall Total		301	284	297	292	289	282

Table: 4
Estimated CNs in different AMC conditions of storm group for different conservation measures

AMC	Storm group	NCM	IBT	ST	PT	RT	GVB
	Small	76.7	78.22	78.48	77.58	77.86	87.21
I	Medium	78.14	67.25	67.25	71.96	71.96	80.27
	Large	77.32	81.98	80.61	79.24	80.61	90.09
	Average CNs	77.39	75.82	75.45	76.26	76.81	85.86
	Small	77.97	81.99	82.11	81.7	81.83	91.54
II	Medium	78.34	76.84	76.84	79.1	79.1	88.33
	Large	-	-	-	-	-	-
	Average CNs	78.16	79.42	79.48	80.40	80.47	89.94
	Small	79.03	84.02	84.07	83.92	83.96	93.88
III	Medium	79.48	82	82	82.94	82.94	92.67
	Large	79.62	84.59	84.39	84.09	84.39	94.32
	Average CNs	79.38	83.54	83.49	83.65	83.76	93.62

groups of storm. Larger number of sets observed for the AMC III compared to AMC-I and II. The CNs of VGB were higher for AMC I, II and III for all storm groups compared to all other conservation measures (Table 4). The lowest CNs observed for NCM for all storm groups and then for all conservation measures. The average CN for AMC-I, II and III are 77.93, 81.31 and 84.57, respectively.

Runoff Estimation and Comparison

Eventwise computation of runoff by Curve number method shows closely estimation compared to observed value. The event wise daily estimated and observed runoff from different conservation is presented in Fig.1(a-f).

The Regression coefficient (R^2) for all conservation measures were varies from 0.85 to 0.95. The lowest R^2 was observed for NCM treatment and all were close with not much deviation. The RMSR were observed for all conservation measure ranging between 2.97 to 4.67. This positive value indicates the overestimation of runoff by estimated curve numbers. The deviation in estimated and observed runoff found, because of Curve number are

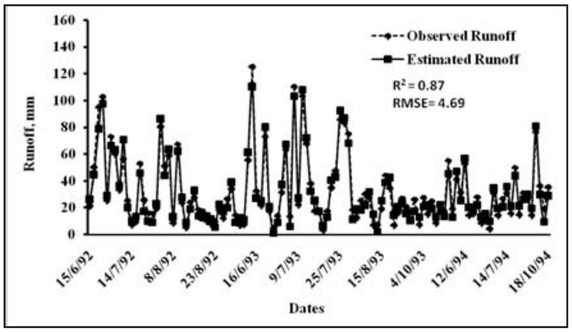

Fig.1(a) Observed and estimated runoff from NCM for duration of 1992 to 1994

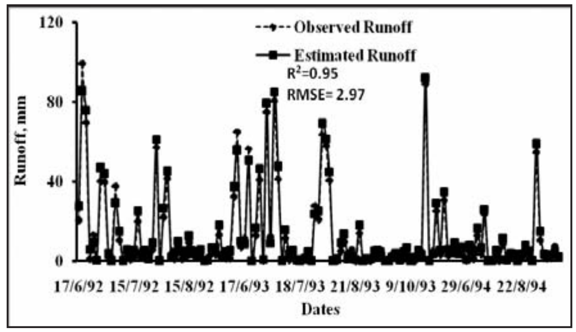

Fig.1(b) Observed and estimated runoff from IBT for duration of 1992 to 1994

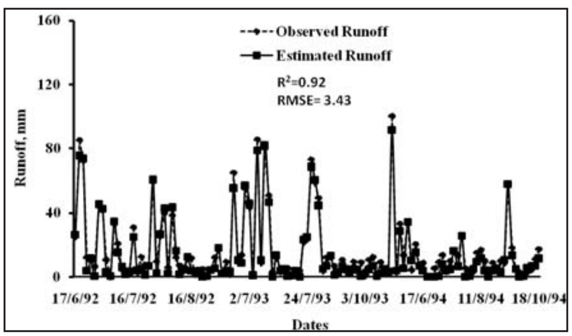

Fig.1(c) Observed and estimated runoff from ST for duration of 1992 to 1994

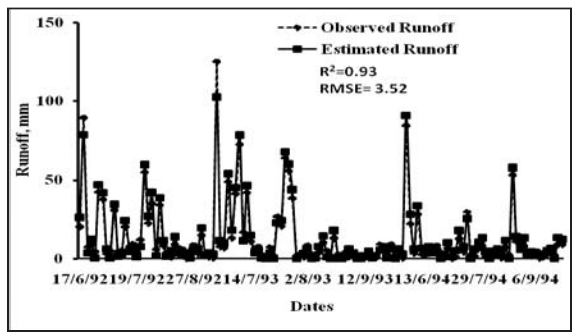

Fig.1(d) Observed and estimated runoff from PT for duration of 1992 to 1994

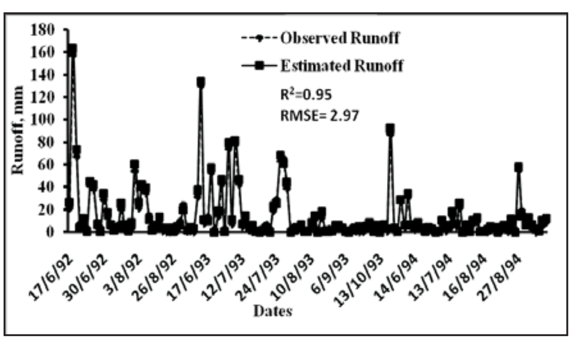

Fig.1(e) Observed and estimated runoff from RT for duration of 1992 to 1994

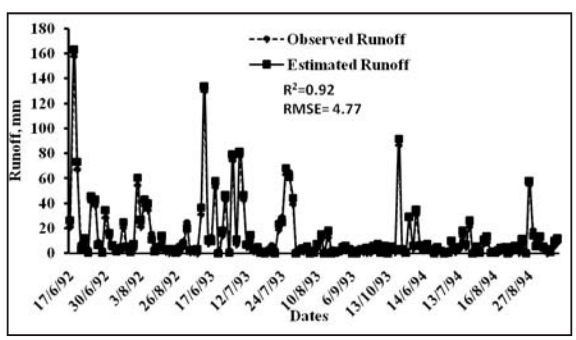

Fig.1(f) Observed and estimated runoff from VGB for duration of 1992 to 1994

Fig. 1. Daily observed and estimated runoff from all conservation measures (NCM, IBT, PT, RT, ST, VGB)

asymptotic in nature. The accuracy of CN method totally dependent on the selection of proper CNs value. If CNs is not properly chosen from standard table or estimated with other methods, error in estimation of runoff found very much. Hence, whatever the difference found in observed and computed runoff due to so.

Monthly observed runoff and computed runoff by lognormal Curve Number method nearly matching each others for all conservation measures (Table 5). The standard deviation between observed and estimated was found less in case of Platform terraces (129.13) compared to the other conservation measures, whereas standard error for IBT, RT and ST were nearly the same. The average annual observed runoff was found more in case of NCM and VGB compared to other conservation measures and same trend was observed in case of estimated runoff by CNs methods (Table 5).

The Standard Error observed was 36.28, 5.26, 19.00, 20.65, 1.68 and 30.64 for NCM, IBT, ST, PT, RT, and VGB, respectively. The t-test was applied to monthly observed

Table: 5
Monthly observed and computed runoff for all conservation measures of ARS, Mulde

Month	NCM		IBT		ST		PT		RT		GVB	
	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.
Year						1992						
June	607.98	615.32	384.40	409.89	446.71	404.21	316.14	334.24	385.11	408.42	580.77	611.08
July	252.1	228.44	111.8	128.18	157.66	127.41	117.74	107.36	109.38	127.27	227.92	246.72
August	420.9	413.15	124.2	140.49	199.95	179.39	164.25	182.02	165.68	181.13	342.40	370.54
Sept	28.9	32.61	7.06	8.10	12.92	8.63	4.82	7.93	1.83	8.00	31.77	41.31
Annual Q	1309.83	1289.51	627.40	686.66	817.24	719.64	602.95	631.55	662.00	724.82	1182.86	1269.65
Year						1993						
June	393.84	386.69	238.68	248.36	211.5	210.09	190.49	207.69	237.1	248.8	354.56	377.87
July	861.44	844.69	493.78	534.06	528.98	515.21	435.55	450.77	519.6	546.4	860.12	891.63
August	160.52	126.04	39.47	41.01	47.17	31.31	52.41	47.57	43.79	46.51	119.95	152.11
Sept	148.95	123.96	16.70	20.86	28.73	12.19	17.37	18.27	20.14	26.2	74.25	98.49
Oct	117.75	106.38	14.49	21.60	40.74	23.55	28.70	30.03	19.56	31.09	70.17	87.21
Annual Q	1682.50	1587.76	803.11	865.90	857.13	792.35	724.52	754.33	840.22	899.01	1479.05	1607.31
Year						1994						
June	336	345.31	176.3	191.04	237.05	193.83	164.76	189.63	172.1	195.8	348.2	370.91
July	213.9	208.81	58.75	76.13	108.5	82.46	64.54	82.83	65.78	86.79	205.4	221.92
August	152.7	155.79	76.81	91.61	136.5	119.19	106.21	132.51	123	141.5	315.7	340.93
Sept	18.91	6.35	12.41	14.81	5.88	5.50	13.56	26.73	5.32	9.52	16.23	24.41
Oct	35.25	28.69	3.08	1.73	33.06	25.04	20.10	25.81	14.86	21.75	38.79	52.35
Annual Q	756.74	744.944	327.37	375.307	520.95	426.022	369.17	457.51	381.04	455.37	924.26	1010.52
STDEV	240.89		156.60		158.28		129.13		158.17		241.99	
SE	13.20		5.25		12.94		10.16		5.32		5.76	
F-cal	1.01		1.14		1.07		1.08		1.08		1.05	
F-table	2.50		2.50		2.50		2.50		2.50		2.50	
t-cal	0.10		0.21		0.31		0.21		0.23		0.24	
t-table	2.16		2.16		2.16		2.16		2.16		2.16	
Sig. of test	NS		NS		NS		NS		NS		NS	

NS* -Non significance at 5% level of confidence; Obs. - Observed; Comp. - Computed.

and estimated runoff data set. It was observed that observed and estimated runoff has non-significant difference at 5% level of confidence. Though, the annual observed and estimated runoff not showing significant difference for some of statistical parameter, monthly observed and estimated shows goodness of fit with all statistical parameters. This is due to that some of dormant season month (September and October) produce less runoff or runoff-causing event observed very less. Other reason may be vegetative cover in above months high due to actual runoff observed very less i.e. change in hydrologic condition. This change in hydrologic condition not accounted in the estimated runoff by SCS CN method. Therefore, some of the events show more difference in observed and estimated runoff. But overall the performance of SCS CN method for estimation of runoff from all conservation measures was found satisfactory.

4. CONCLUSIONS

In the present study, CNs were estimated by lognormal methods from rainfall data of 1992 to 1998 (seven) years for different conservation measures. Small storm group has large number of runoff causing events in all AMCs compared to medium and large storm groups. The CNs values for different conservation measures are different due to different runoff causing events in each group. The performance of CNs for all storm AMC groups under different soil conservation measures showed that there is no significant difference between observed and computed runoff. The lowest runoff was observed from the intermittent bench terracing whereas Platform terrace has maximum runoff harvesting capability compare to the Vetiver grass bunds and ring terracing. Hence, Computed CNs can be used for estimation of runoff from ungauged watershed.

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