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Rainfall-runoff relationship based on the model of runoff formation at the natural storage*

R. N. ADHIKARI, S. CHATTARAJAN, U. S. PATNAIK and M. M. SRIVASTAVA

Central Soil & Water Conservation Research & Training Institute, Bellary

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सार — वर्षा और जल-वाह के मध्य सम्बन्ध स्थापित करने का प्रयास किया गया है । (1) वर्षा, (2) जल-वाह और (3) वाष्पोत्सर्जन आधारभूत निवेश आंकड़े हैं। विचाराधीन वर्षा से पूर्व नमी की मात्रा और वर्षा के समाप्त होने के बाद की मात्रा का जल सन्तुलन तकनीक द्वारा परिकलन किया गया है । यह पद्धति कर्नाटक के बेलारी में स्थित मृदा संरक्षण अनुसंधान फार्म में छोटे कृषि जलग्रहण में अपनाई गई जिसे काली मिट्टी के प्रदेश के अर्द्ध-शुष्क अंचल के रूप में वर्गीकृत किया गया है। विभिन्न आरम्भिक नमी-मात्रा और वर्षा-घनत्व के अन्तर्गत वर्षा और जल-वाह के मध्य सम्बन्ध का पता लगाया गया है। वर्षा के समाप्त होने के बाद जलग्रहण में नमी की स्थिति तथा, अतिरिक्त कारक के रूप में वर्षा की तीव्रता सहित, जल-वाह के मध्य के संबंध का पता लगाने का भी प्रयास किया गया है। विभिन्न समीकरणों से प्राप्त आकलित जल-वाहों (अपवाहों) की तुलना प्रेक्षित जल-वाह से की गई। तीसरे प्राचल के रूप में आरम्भिक नमी मात्रा सहित वर्षा और जल-वाह सम्बंध जलवाह के आकलन के लिए प्रोत्साहक परिणाम प्रस्तुत करते हैं ।

ABSTRACT. An attempt is made to establish a relationship between rainfall and runoff. The basic input data are (*i*) rainfall, (*ii*) run off and (*iii*) evapotranspiration. The moisture content prior to rainfall under consideration and after the termination of rainfall is computed by water balance technique. This method is applied in small agricultural catchments in Soil Conservation Research Farm at Ballary, Karnataka, which is categorised as semi-arid zone of black soil region. The relationship between rainfall and runoff under different initial moisture content and rainfall intensities are found out. Attempts are also made to get relationship between moisture condition of the catchment after the end of rainfall and runoff with rainfall intensities as an additional factor. The estimated runoff obtained from various equations are compared with the observed runoff. The rainfall-runoff relationship with initial moisture content as third parameter gives encouraging results for estimation of runoff.

1. Introduction

The concept of runoff formation at the natural storage may be governed by (*i*) amount of rainfall, (*ii*) intensity of rainfall and (*iii*) available soil moisture at the beginning of the rainfall. A simple water balance equation :

$$P_t - R_t - E_t = W_{0,(t+1)} - W_{0,t} \qquad (1)$$

where $W_{0,t}$ is the moisture storage at the beginning of rainfall. $W_{0,(t+1)}$ is the moisture storage at the termination of the rainfall. E_t, P_t, R_t are the observed evapotraspiration, rainfall and corresponding runoff, may be used to express the rainfall-runoff relation. It may be pointed out that Eqn. (1) holds good for one single portion of the entire watershed. The climatic, geographic, geologic and other conditions lead to the complexity of runoff formation from rainfall. Generally speaking, dry seasons are mainly characterised by runoff formation in excess of infiltration, whereas wet seasons are responsible for runoff formation at the natural storage. The complexity also arises in the case of moisture deficit if the aeration zone is thin. At these places where the soil layer is thick and the ground watertable is at considerable depth, the aeration zone is thick. The non-uniform distribution of moisture deficit in the aeration zone of a watershed brings about the difference in the amount and beginning time of runoff yield at different places during rainfall (Anonymous 1977). But in our case we have taken a single point small catchment in our research farm, where it is assumed that the homogeneity will exist. Hence, for a particular watershed for a given flood, it is imperative to acquire understanding about the specific conditions and make analysis accordingly in order to find out the correct way to solve the problems.

2. Data used and area of study

From 1978 to 1981 daily E_t and rainfall data from meteorological observatory situated at the research farm and daily runoff data from a small plot is obtained and used as basic data for this study. The study area considered is a small agricultural plot of jowar crop of area 2250 m² in Central Soil & Water Conservation Research & Training Institute's Research Farm located in semi-arid zone, Bellary in the State of Karnataka (Anonymous 1982).

3. Methodology

The computation of $W_{0,t}$ have begun after the end of long spell of rainless period and then proceeded day by day to obtain for all days in rainy season as per

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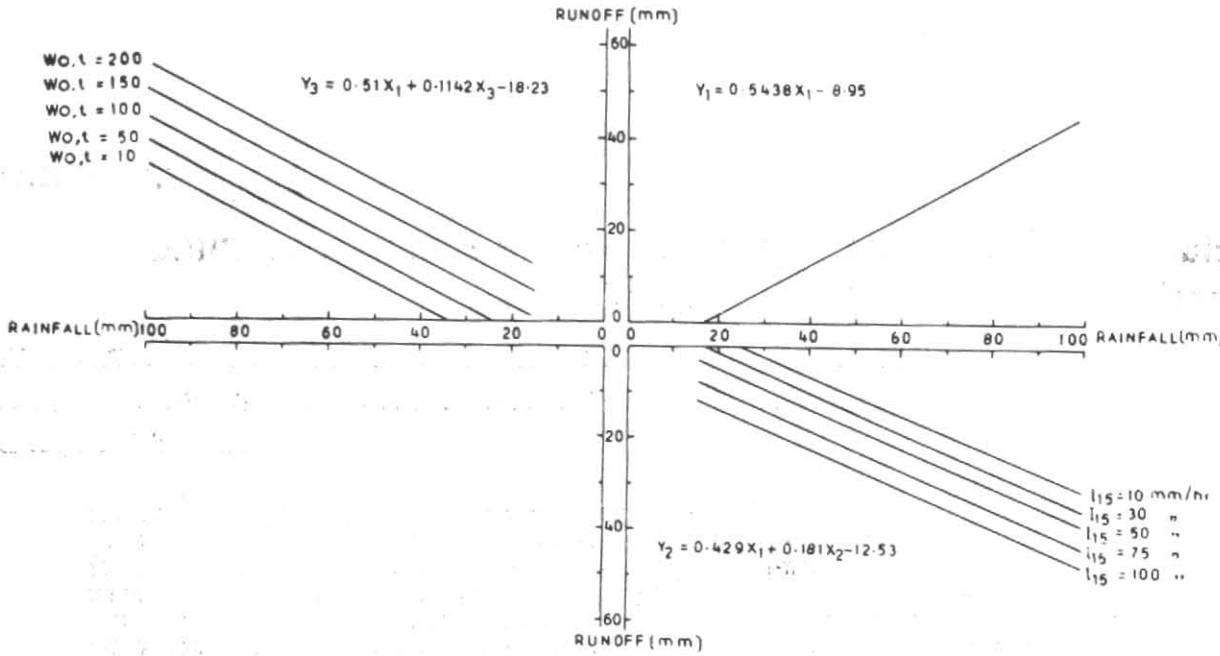

Fig. 1. Rainfall-runoff relationship with initial moisture and 15-min. maximum intensity as additional factor

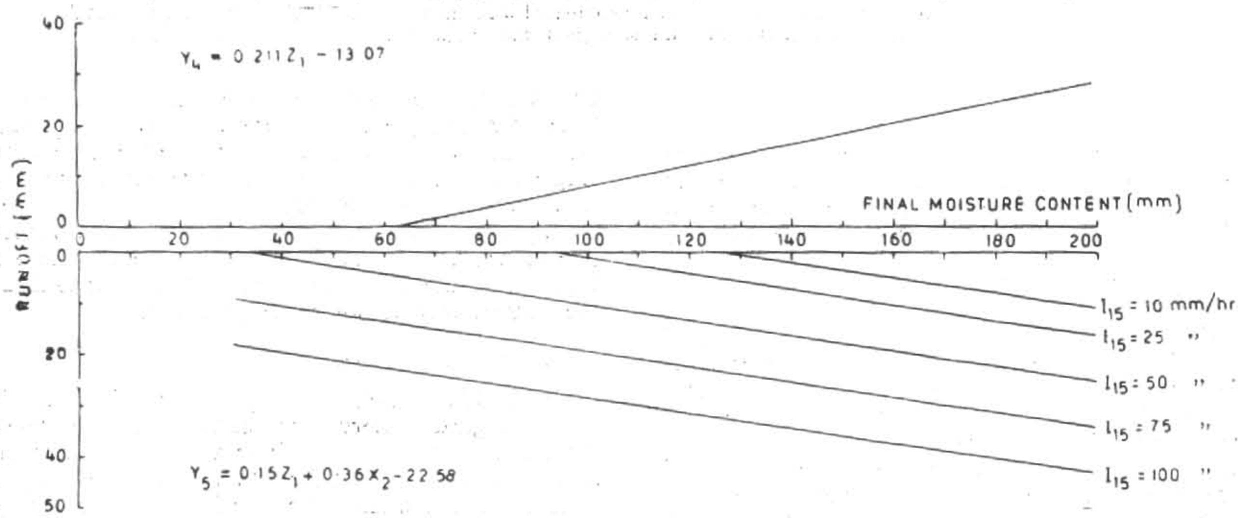

Fig. 2. Final moisture-runoff relationship with max. 15-min. intensity as additional factor

equation :

$$W_{0\cdot(t+1)} = W_{0\cdot t} + P_t - R_t - E_t \qquad (2)$$

where, $W_{0\cdot t}$ indicates the moisture storages at the beginning of $t_{0\cdot t}$ day. P_t is the rainfall amount on the t^{th} day. R_t is the runoff amount generated from P_t. E_t is watershed evapotranspiration on the t^{th} day.

$W_{0\cdot(t+1)}$ is considered moisture available after the end of rainfall. To begin with all the right hand portion assumed zero and then ;

$$W_{0\cdot(t+1)} = W_{0\cdot t} - E_t \quad \text{for rainless day where } P_t = 0 \qquad (3)$$

$$W_{0\cdot(t+1)} = W_{0\cdot t} + P_t - E_t \quad \text{for } nil \text{ runoff situation} \qquad (4)$$

The value of $W_{0\cdot(t+1)}$ and $W_{0\cdot t}$ will be available for every rainfall and runoff situation that has occurred in September-November period. One sample calculation is presented Sec. 4.

TABLE 1

Rainfall, runoff and other related components

Date	Rainfall (mm)	Max. 15 min. intensity (mm/hr)	Rainfall evapo-transpiration (mm)	$W_{0,t}$ (Initial moisture content) (mm)	$W_{0,t+1}$ (Final moisture content) (mm)	Runoff* (mm)
21 Sep 78	26.5	40.0	25.3	31.8	57.1	1.4
27 Sep 78	43.6	56.0	39.1	62.5	101.6	2.9
28 Sep 78	30.7	32.0	25.7	98.7	124.4	1.7
29 Sep 78	22.4	30.0	17.4	122.7	140.1	1.1
30 Sep 78	75.3	55.2	69.8	139.0	208.8	38.9
8 Sep 79	32.6	59.6	30.1	7.0	37.1	1.4
23 Sep 79	34.8	24.4	31.8	44.3	76.1	0.8
2 Sep 81	66.6	33.6	64.1	23.1	87.2	16.5
4 Sep 81	30.0	28.0	28.6	67.7	96.3	6.0
11 Sep 81	30.6	51.6	29.6	79.0	108.6	7.7
12 Sep 81	34.8	44.8	31.3	100.9	132.2	22.2
17 Sep 81	79.7	80.0	65.7	98.0	163.7	36.7
18 Sep 81	41.8	46.0	36.8	127.0	163.8	27.2
19 Sep 81	59.2	86.0	53.2	136.6	189.8	41.4
24 Sep 81	18.6	34.8	15.1	139.5	154.6	9.7
6 Oct 81	105.2	72.0	95.2	127.5	222.7	43.1
9 Oct 81	25.6	41.2	17.2	169.9	187.1	5.7
1 Nov 81	51.6	74.0	51.5	133.9	185.4	14.7

*Runoff data is obtained from this Centre's Annual Report 1982 from an experiment conducted by U.S. Patnaik *et al.*

4. Sample calculations

As per daily rainfall record it is observed that on 23 July 1981 rainfall occurred was 3.3 mm and before that there was a long spell of rainless period. For 1981 from 23 July we can start our calculation as follows with assumption that initial moisture, $W_{0,t}=0.0$:

$$W_{0,(t+1)} = P+W_{0,t}-E_t \qquad (5)$$

23 July 1981: $W_{0,(t+1)} = 3.3+0-0.2=3.1$

($E_t=0.2$ mm observed)

so 3.1 mm will be $W_{0,t}$ for next day, *i.e.*, 24 July.

24 July 1981 : $W_{0,(t+1)}=1.6+3.1-1.8=2.9$

(rainfall$=1.6$ mm and $E_t=1.8$ mm observed)

so 2.9 mm will be $W_{0,t}$ for next day, *i.e.*, 25 July.

25 July 1981 : $W_{0,(t+1)}=0.0+2.9-1.7=1.7$

(No rainfall and $E_t=1.7$ mm observed)

and so on

2 Sep 1981 : $W_{0,(t+1)}=66.6+23.1-2.5=87.2$

where 66.6 mm & 2.5 mm are observed rainfall and evapotranspiration and 23.1 mm is the initial moisture carried over from earlier period to this date.

3 Sep 1981 : $W_{0,(t+1)}=0.4+87.2-3.4-16.5=67.7$ mm

where 0.4 mm and 3.4 mm are observed rainfall and E_t and 16.5 mm runoff has occurred on 2 September.

5. Results and discussion

Day to day calculations for $W_{0,t}$ (initial moisture content in mm) and $W_{0,(t+1)}$ (final moisture content in mm) from the observed rainfall, evapotranspiration, and runoff data are made. Table 1 shows all the runoff causing rainfall events alongwith computed values of maximum 15 min. intensity (I_{15}), initial moisture content, $W_{0,t}$ and final moisture content, $W_{0,(t+1)}$.

TABLE 2

Observed and estimated runoff under different situations

Y	Y_1	Y_2	Y_3	Y_4	Y_5
1.4	5.46	6.08	0.0	0.00	0.4
2.9	14.76	16.31	11.2	8.37	12.8
1.7	7.75	6.43	8.7	13.18	7.6
1.1	3.23	2.51	7.2	16.49	9.2
38.9	32.00	29.77	36.1	31.00	28.6
1.4	8.78	12.24	0.0	0.00	4.4
0.8	9.97	6.82	4.6	3.00	0.0
16.5	27.27	22.12	18.4	5.33	2.6
6.0	7.36	5.41	4.8	7.25	1.9
7.7	7.69	9.94	6.4	9.85	12.3
22.2	9.97	10.51	11.1	14.82	13.4
36.7	34.39	36.14	33.6	21.47	30.8
27.2	13.78	13.73	17.6	21.49	18.6
41.4	23.24	28.43	27.6	26.98	36.8
9.7	1.17	1.75	7.0	19.55	13.1
43.1	48.26	45.63	50.0	33.92	36.7
5.7	4.97	6.63	14.3	26.41	20.3
14.7	19.11	23.00	23.4	26.05	31.9

Remarks : Correlation coefficient between Y and Y_1 is 0.826, Y and Y_2 is 0.851, Y and Y_3 is 0.895, Y and Y_4 is 0.737 and Y and Y_5 is 0.822

Note : Y=Observed runoff in mm and Y_1 to Y_5 is estimated runoff from equations :

$$Y_1=0.5438\ X_1-8.95 \qquad (6)$$

$$Y_2=0.429\ X_1+0.181\ X_2-12.53 \qquad (7)$$

$$Y_3=0.51\ X_1+0.1142\ X_3-18.23 \qquad (8)$$

$$Y_4=0.211\ Z_1-13.07 \qquad (9)$$

$$Y_5=0.15\ Z_1+0.36\ X_2-22.58 \qquad (10)$$

where X_1=Rainfall in mm, X_2=Maximum 15 minute intensity in mm/hr, X_3=Intitial moisture content in mm Z_1=Final moisture content in mm and Y_1 to Y_5=Runoff in mm

A set of regression and multiple regression equations have been developed for prediction of runoff from various related parameters. The equations developed are shown in Table 2. The equations are also represented graphically in Figs. 1 & 2. Rainfall runoff relationship with initial moisture content (mm) and maximum 15 min. intensity, as an additional factor, are shown in Fig. 1. Runoff obtained from various equations alongwith the observed runoff are presented in Table 2. The correlation coefficients between observed and estimated runoff (obtained from different equations) are also presented. The differences of observed and estimated runoff values with respect to 45° angle line are shown in Fig. 3. Correlation coefficient is noticed to be maximum (0.895) for rainfall runoff relationship with initial moisture content as an additional factor [Eqn. (8) followed by Eqns. (6) & (7)]. Final moisture content-runoff relationship with maximum 15 minute intensity as an additional factor [Eqn.(10)] gives better correlation coefficient than Eqn. (9). It is observed from the analysis that in micro-catchments (less than one hectare area), the average

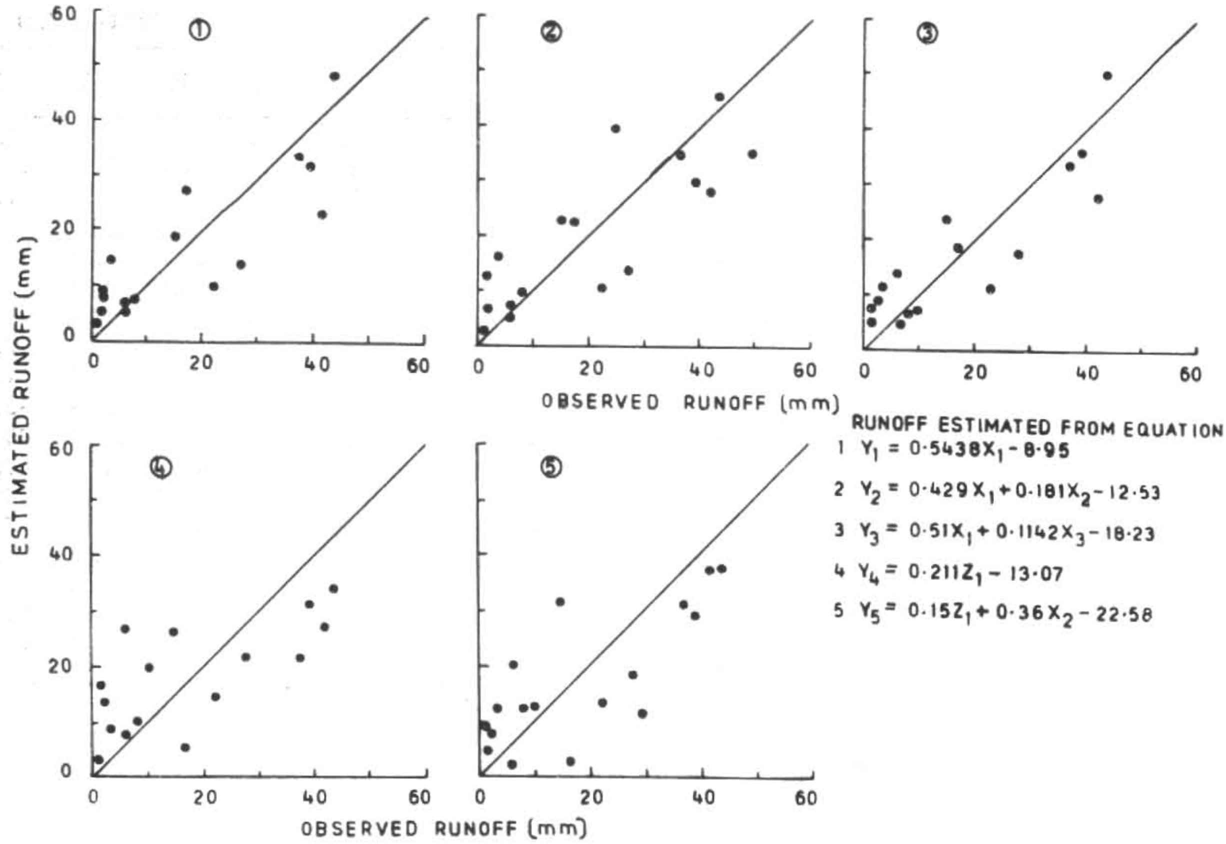

Fig. 3. Comparison of observed and estimated runoff using different equations with reference to 45° line for best fit

intensity for entire rainfall period for production of runoff is less effective than high intense rainfall in small periods (15 min maximum intensity). This term is often used for estimating soil erodibility factor for prediction of soil erosion and runoff. Since soil loss data for every individual storm is not available for this study, no attempt is made on prediction of soil loss. It is also noticed that high antecedent moisture content prior to rainfall under consideration is one of the major tools for generating runoff from this type of soil. If the soil dries and develops cracks, very high infiltration rate is recorded. Once the cracks are filled up and top soil gets sufficiently wet, infiltration rate will be significantly reduced generating more and more runoff from the catchment areas. A relation between moisture status of the catchment after the termination of rainfall (final moisture content) and runoff with various additional factors is also attempted, but good correlation was observed only for maximum 15 min intensity as an additional factor. The equation developed for rainfall runoff relationship and final moisture content runoff relationship will hold good only for runoff producing rainfall event. The same equations may be utilised for other similar catchments with assumptions that atleast 18 mm and 37 mm rainfall and final moisture content is required to produce runoff.

6. Utility of the model

(*i*) To identify the extent of runoff from every storm, hydrology based model is useful. The hydrological models are among the most sophisticated tools available for the analyzing water resource issues. The information so collected from one catchment will help to serve in generating data, basic input to all future plans in similar agroclimatic regions.

(*ii*) In arid and semi-arid zones, where water harvesting techniques can be applied to use surface runoff for agricultural production. The rainfall runoff modelling can be used to know the potential of runoff from agricultural watersheds and small farm catchments for designing water harvesting systems.

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