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INFLUENCE OF CONSERVATION MEASURES ON WATER YIELD FROM CATCHMENTS IN THE SEMI-ARID TRACT OF SOUTH INDIA

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ABSTRACT

Hydrological monitoring of a watershed at Chinnatekur, Kurnool District (Andhra Pradesh) in the semi-arid zone of peninsular India, shows that runoff and soil loss from watersheds treated with conservation measures such as contour trenches are reduced by more than 100% when compared to an untreated watershed. Soil and water conservation measures improved ground water recharge, resulting in a 36% increase in crop area which could be irrigated by wells, which helped to increase crop yields by 69%. Detailed analysis of rainfall, rainfall-runoff relationship, water balance of the watershed and ground water recharge are discussed.

INTRODUCTION

Increases in food production in India mostly have come from the irrigation of plains, and progress has reached a plateau. Rain-fed uplands and drylands need increased cultivation to contribute to future food production (Ferrar & Craswell, 1988). Soil and water conservation and management will play a crucial role in increasing crop production from such areas (Randhawa, 1981). But it is estimated that about 45% of the land suffers from serious soil erosion by water and wind (Das, 1985). In India, of the 4000 km^3 of rainfall received, 1800 km^3 is lost as surface runoff, causing erosion of top soil. Soil loss, due to agriculture and associated activities, is estimated to be about 5333 m t per annum. Of this, 29% is carried away by rivers into the sea and 10% is deposited in surface reservoirs (Dhruvanarayana & Rambabu, 1983), causing land degradation and environmental pollution.

Scientific management of resources using appropriate conservation measures within watersheds is needed to solve the problems of environmental degradation and declining productivity. Studies conducted in the North Eastern Hill region of India indicate that 80 to 100% of the rainfall can be retained *in situ* by adopting watershed-based farming methods (Singh, 1986). This permits successful rain-fed agriculture and also increases groundwater recharge. To test conservation measures, a watershed covering an area of 1120 ha was selected, at Chinnatekur (Kurnool district, Andhra Pradesh) in South India. A watershed development programme, comprising various conservation measures for arable and non-arable lands, was organised between 1984 and 1986 and was continuously monitored for hydrological changes. The results are presented in this paper.

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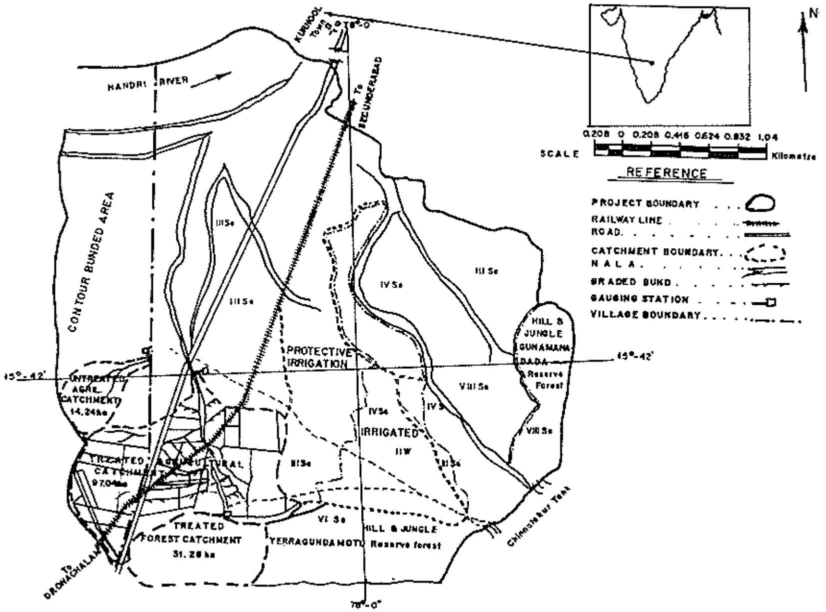

FIG. 1—Location of Chinnatekur, Kurnool (Taluk & District), showing microcatchments.

THE STUDY AREA

The Chinnatekur watershed is located 12 km from Kurnool in Andhra Pradesh, at latitude 15° 42' N and longitude, 78° 0' E. The altitude across the watershed varies from 390 m at the lowest point to 465 m at the highest point. Chinnatekur village is located at an altitude of 393 m inside the watershed. The topography is undulating with a general slope to the north with a fall for arable lands of 24 m. It is bounded by low hills on the eastern and southern sides and by the Handri River on the northern side. The entire watershed is drained by two gullies joining the Handri River. As average rainfall is low, 654 mm, dryland agriculture is the major land use. To bring about sustainable agricultural development of the watershed, a master plan was prepared based on principles of ecology, economics, employment generation, and resource conservation in co-ordination with local people and government departments. This involved studying climate, land, water and plants on one hand, and man and animal resources and their needs on the other.

METHODS

Rainfall data for 23 years (1960–82) for the town of Kurnool was subjected to probability analysis following Gumbel (1958) to identify the frequency of dry and wet spells, the growing season, and to decide the type of conservation measures required.

A soil map of the area was prepared to demarcate non-arable lands and arable lands and choose, depending upon their limitations, appropriate conservation measures that are economical for the region.

A geological survey was undertaken to determine the groundwater potential, and to decide strategies to enhance groundwater recharge.

A vegetation survey was made to identify species which are native to the area, economical, and useful for arresting runoff.

A topographic survey was undertaken to select appropriate conservation measures for drainage and conservation of rain water.

Based on these surveys, and taking into account the socio-economic conditions of the people living in the area, a development plan was prepared with the following conservation measures:

- Construction of diversion drains (*bunds*) at the base of the hills for safe disposal of runoff from the hills.
- Construction of staggered contour trenches of 4m x 1m x 0.5m, at 10m horizontal intervals with 1m spacing between trenches. Different tree species were planted on the trench mounds 1m apart initially, and thinned later to 3m spacings between plants in a row.
- On arable lands, construction of graded *bunds*, 0.75 sq.m in cross section, at 1.0m vertical intervals, supported by stone checks and draining into natural waterways and farm ponds.
- Construction of rock-fill dams, *nala bund* (small earthen dams for water storage and erosion prevention) and arch weirs for controlling gullies.
- Stream-bank control using vegetation and stone pitching.
- Construction of field channels and drains in irrigated areas.

Following treatments, three smaller watersheds within the southeastern section of the main watershed were selected (Fig.1) for evaluating hydrological changes. Catchment characteristics of the three small watersheds are given in Table 1.

Gauging stations were constructed at the end of each catchment and F-type Stevenson water-level recorders were installed to gauge runoff. Rainfall was measured using an automatic raingauge conforming to Indian Meteorological Department (IMD) standards. Samples were collected after each runoff event manually for measurement of sediment concentrations.

In order to assess the influence of conservation measures on runoff detention and groundwater recharge, water levels in 47 open wells in the watershed were monitored manually every week, along with a well adjacent to the watershed as a control. Information on areas cropped around each well, both inside and outside of the watershed, was collected during 1984, the pre-treatment period, and continuously after treatment to determine the availability of additional groundwater from recharge.

Annual water balance for the three catchments was computed for the years 1987 to 1990, using the formula $P = R + E + S$, where P is precipitation, R is runoff, E is evapotranspiration and S is groundwater recharge. Annual precipitation over the watershed was used for precipitation (P) and the volumes of runoff from individual events were added to get the total runoff (R) for the year. The balance of P–R was assumed to have gone into the soil and been lost or utilised either as evapotranspiration (E) or groundwater recharge (S). For separating E and S, the potential evapotranspiration (PE) of the station (published by IMD, Pune) was used. When P–R was more than PE, the excess was considered to be groundwater recharge and when P–R was less than PE,

TABLE 1—Catchment characteristics of the treated forest, treated agricultural and untreated agricultural catchments, Chinnatekur watershed.

Catchment character	Treated Forest catchment	Treated Agricultural catchment	Untreated Agricultural catchment
Area (A) ha.	31.28	97.05	14.24
Perimeter (P) m	2720	5640	1550
Length of main stream (L) m	1150	1424	743
Difference in elevation between highest and outlet point (H) m	50	20	9
Average width of catchment (W) = A/L m	272	682	192
Farm factor (F) = W/L	0.24	0.48	0.26
Compactness coefficient (C+)	1.36	1.60	1.15
Time of concentration (Tc*) minutes	15	27	17

$$^{+}C = \frac{0.28\,P}{\sqrt{A \times 10000}}$$

$$^{*}Tc = \frac{0.01947\,L^{0.77}}{S^{0.385}}$$

S is the slope of the catchment

the entire amount was taken as actual evapotranspiration (AE). Monthly values were totalled to arrive at the annual value of E and S.

The forest catchment, of land-capability classification VI Se, with limitations of soil depth and steep slope (State Soil Survey Dept., Andhra Pradesh, 1982) was planted with 3280 trees/shrubs, such as *Acacia nilotica, A.planifrons, Hardwickia binata, Azadirachta indica, Zizyphus species, Carissa caraudus* etc. The planting was done over the trench mounds after forming staggered contour trenches.

The treatment for treated agricultural watershed of land capability class III Se (State Soil Survey Dept., Andhra Pradesh, 1982) consisted of graded *bunds* of 0.75 sq.m. cross section at 1.0m vertical intervals, with variable grades of 0.1 to 0.2%, connected to waterways and gullies to drain excess rainwater. Groundnut/Sunflower/*Jowar*/*Setaria* are grown in the area, using improved dryland technology.

A small watershed belonging to land capability class III Se (State Soil Survey Dept., Andrah Pradesh, 1982), left untreated to serve as control, was also gauged. The crops grown and practices followed were the same as those in the treated agricultural watershed.

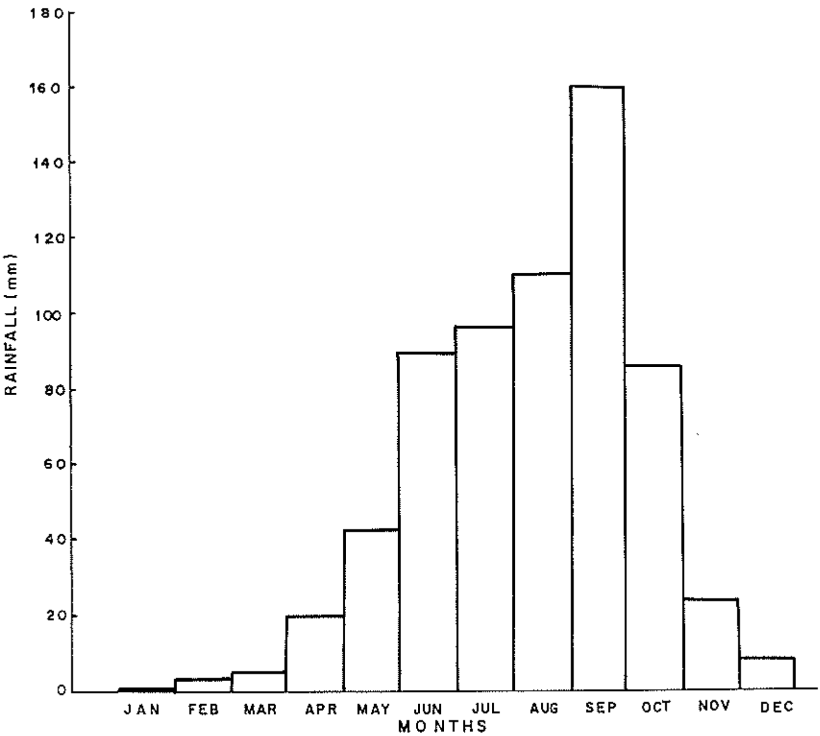

FIG. 2—Mean monthly rainfall at Kurnool.

Simple and multiple regression equations were developed for prediction of runoff and peak rate of runoff, using rainfall and related parameters such as intensity, duration, and antecedent rainfall.

RESULTS AND DISCUSSION

Rainfall

The distribution of rainfall (Fig.2) is fairly good for crop production between June and October. Mean monthly rainfalls during May through October were 43.0, 90.8, 97.6, 110.1, 161.5 and 87.9 mm, with coefficients of variation of 106.9, 45.0, 58.2, 74.9, 69.7 and 92.4 respectively. The chance of receiving 100 mm or more is 60.9% in August, and is as high as 65.2% in September.

Rainfall data was analysed for periods of one week. Standard Met. week 24 (June 11 to 17) records an average rainfall of 30 mm, and week No. 37 (Sept 10 to 16) receives a rainfall of 60 mm. Analysis of weekly rainfall has indicated a 52% or more probability of recording 10 mm or more for the 23rd to 39th standard Met. weeks (4th June to 30th September), while it is 47.8% in the 39th week (24th to 30th September) for rainfall of more than 50 mm.

TABLE 2—Return period analysis for different durations of rainfall

Return period (years)	Rainfall (mm) Daily	Weekly	Monthly
2	77	129	195
5	104	172	275
10	122	200	329
25	145	236	397
50	161	262	447

N.B. Mean annual rainfall is 654.0 mm.

Return periods for daily, weekly and monthly rainfall (mm) were analysed following Gumbel, 1958. The results are presented in Table 2.

Maximum daily rainfall varies from 77 to 161 mm for return periods ranging from 2 to 50 years (Table 2). These rainfalls could be erosive, as the total water-holding capacity of the soil is between 100 and 200 mm. Soil conservation measures, such as graded *bunds,* gully control structures and water-harvesting systems like farm ponds, are designed to cope with storms having a return period of 5 to 25 years.

Rainfall-Runoff Relationships

Rainfall recorded at the project site during 1986 to 1990 did not differ significantly from rainfall recorded at Kurnool (13 km from the project) with respect to weekly, monthly and annual values. This supports the suitability of conservation strategies and crop planning adopted in the project based on analysis of Kurnool rainfalls.

During the study period, 12, 14, 11 and 6 runoff events occurred during 1987, 1988, 1989 and 1990 respectively. Over those years, there were only 6 major runoff-producing rainstorms of 50 mm or above per day, one each in 1987 and 1988 and two each in 1989 and 1990. The highest rainfall, 129 mm in one day, occurred on 11th July 1988 (with return period of 15 years) and another of 109.2 mm (with a return period of 7 years) on 7th June 1989.

For all the events during the period (Table 3), the runoff and peak rate of runoff were correlated with rainfall, as observed by Sastry and Dhruvanarayana, (1984), and with antecedent rainfall, intensity and duration. Based on the high coefficients of correlation ($r \geq = 0.8$), the following regression equations were developed for the three catchments:

(A) Treated Forest Watershed

$$Y = 0.00273\ X_1 + 0.0689\ X_2 - 0.148\ X_3 + 0.152 \text{ (Std. Error of Est. = 1.7)}$$

$$Y_1 = 0.268\ X_1 - 3.548 \text{ (Std. error of Est. = 6.7)}$$

TABLE 3—Rainfall runoff data of Chinnatekur watershed (Kurnool District) (1987–90)

Date	SLNO	Rainfall (mm)	Intensity (mm/hr)	Duration (hrs)	5 Day API (mm)	Treated Forest Catchment		Treated Agricultural Catchment		Untreated Agricultural Catchment	
						Runoff (mm)	Peak Rate (l/sec/ha)	Runoff (mm)	Peak Rate (l/sec/ha)	Runoff (mm)	Peak Rate (l/sec/ha)
20.06.87	1	15.2	N.R.	N.R.	0.0	0.61	2.11	0.00	0.00	—	—
22.06.87	2	30.0	42.0	2.25	24.4	2.00	7.80	N.R.	N.R.	—	—
07.08.87	3	26.0	N.R.	N.R.	51.4	0.73	1.77	1.31	3.65	—	—
08.08.87	4	28.3	N.R.	N.R.	77.4	1.16	3.14	3.44	11.32	—	—
12.08.87	5	19.3	26.0	3.20	71.9	0.00	0.00	1.44	1.34	—	—
14.08.87	6	7.3	29.2	0.15	36.9	0.04	0.14	0.00	0.00	—	—
15.08.87	7	13.4	N.R.	N.R.	43.0	0.21	0.44	1.13	1.54	—	—
26.09.87	8	14.2	40.0	1.15	11.7	3.52	12.22	3.34	16.80	—	—
06.10.87	9	37.0	80.0	5.55	56.4	4.24	16.20	11.92	40.46	—	—
07.10.87	10	7.1	8.0	4.20	93.4	0.46	0.87	1.33	4.07	—	—
17.10.87	11	46.1	18.0	12.30	6.4	0.27	0.51	2.50	2.58	—	—
04.11.87	12	72.2	42.0	4.25	0.0	1.68	3.45	6.62	9.15	—	—
22.04.88	13	45.0	N.R.	N.R.	0.0	0.38	1.45	0.00	0.00	0.00	0.00
24.04.88	14	21.2	N.R.	N.R.	45.0	0.00	0.00	0.85	1.87	0.00	0.00
22.06.88	15	26.8	N.R.	N.R.	17.0	0.51	1.29	0.27	0.62	0.00	0.00
11.07.88	16	129.0	N.R.	N.R.	6.4	17.64	49.80	N.R.	N.R.	41.57	127.72
15.07.88	17	31.1	N.R.	N.R.	129.0	0.30	0.51	N.R.	N.R.	N.R.	N.R.
16.07.88	18	18.0	N.R.	N.R.	160.1	0.20	0.31	0.40	1.34	N.R.	N.R.
17.07.88	19	28.2	N.R.	N.R.	49.1	0.13	0.31	0.32	0.78	N.R.	N.R.
24.07.88	20	12.4	N.R.	N.R.	2.9	0.05	0.14	0.01	0.04	0.00	0.00
29.07.88	21	31.2	N.R.	N.R.	22.6	0.00	0.00	0.22	0.34	0.00	0.00
03.08.88	22	19.2	N.R.	N.R.	35.5	0.13	0.31	0.08	0.22	0.00	0.00
08.08.88	23	36.2	N.R.	N.R.	34.2	0.61	0.41	0.09	0.22	0.88	1.19
16.08.88	24	20.4	N.R.	N.R.	2.0	0.41	1.29	N.R.	N.R.	0.97	6.18
20.08.88	25	11.0	N.R.	N.R.	38.5	0.05	0.14	0.00	0.00	0.00	0.00
02.09.88	26	35.3	N.R.	N.R.	18.4	0.04	0.31	0.14	0.47	3.50	18.35
28.03.89	27	17.2	48.0	0.30	8.6	6.50	20.16	N.R.	N.R.	8.38	76.68
04.06.89	28	18.2	N.R.	N.R.	11.3	0.08	2.29	1.71	5.94	1.00	8.12
07.06.89	29	109.2	134.0	3.11	37.1	8.77	25.01	20.21	37.37	N.R.	N.R.
13.07.89	30	32.0	26.0	2.35	12.6	4.82	13.83	7.32	16.80	24.60	71.84
16.07.89	31	26.0	15.0	5.00	37.6	0.38	0.41	N.R.	N.R.	1.89	3.88
17.07.89	32	8.1	7.0	2.55	63.6	0.06	0.08	0.11	0.22	2.88	4.98
21.07.89	33	28.2	22.0	6.10	10.4	0.10	0.14	0.09	0.12	N.R.	N.R.
19.08.89	34	4.0	N.R.	N.R.	14.3	0.29	0.62	1.12	4.07	2.05	22.01
01.09.89	35	14.0	N.R.	N.R.	0.0	0.34	0.37	0.48	0.70	0.00	0.00
26.09.89	36	64.2	N.R.	N.R.	7.4	0.81	1.01	N.R.	N.R.	9.92	34.26
07.10.89	37	10.2	N.R.	N.R.	0.0	0.00	0.00	0.00	0.00	1.74	13.29
14.06.90	38	13.1	20.0	0.55	34.0	0.07	0.31	0.16	0.20	0.06	0.33

Date	SLNO	Rainfall (mm)	Intensity (mm/hr)	Duration (hrs)	5 Day API (mm)	Treated Forest Catchment		Treated Agricultural Catchment		Untreated Agricultural Catchment	
						Runoff (mm)	Peak Rate (l/sec/ha)	Runoff (mm)	Peak Rate (l/sec/ha)	Runoff (mm)	Peak Rate (l/sec/ha)
16.07.90	39	51.0	98.0	1.15	4.8	N.R.	N.R.	1.30	1.98	1.49	10.23
23.07.90	40	25.4	76.0	1.30	0.5	N.R.	N.R.	2.63	6.53	2.41	24.90
01.10.90	41	68.4	N.R.	N.R.	21.0	N.R.	N.R.	22.05	29.13	0.00	0.00
02.10.90	42	9.2	N.R.	N.R.	81.0	N.R.	N.R.	0.63	3.13	0.67	1.19
13.10.90	43	32.1	N.R.	N.R.	8.9	0.99	2.47	5.89	16.71	21.04	101.76

Note: Untreated watershed gauged from 1988 only.
N.R. — Data Not Recorded

(B) Treated Agricultural Watershed

$Y = 0.185\ X_1 - 0.198\ X_3 + 0.0582\ X_4 - 3.158$ (Std. Error of Est. = 3.4)

$Y_1 = 0.1225\ X_1 + 0.1925\ X_2 + 0.127\ X_4 - 6.875$ (Std. Error of Est. = 10.8)

(C) Untreated Agricultural Watershed

$Y = 0.288\ X_1 - 3.182$ (Std. Error of Est. = 6.9)

$Y_1 = 0.819\ X_1 - 5.000$ (Std. Error of Est. = 23.7)

Where X_1 = Rainfall in mm

X_2 = 15-minute maximum intensity in mm/hr

X_3 = Duration in hr.

X_4 = Antecedent (5-day) precipitation index, mm

Y = Runoff in mm

Y_1 = Peak rate of runoff in lit./sec./ha

Where data on intensity and duration were not available, the runoff and peak rate of runoff could be predicted by using the following equations:

(D) Treated Forest Watershed

$Y = 0.0964\ X_1 - 1.359$ with $r = 0.8$, Std. Error of Est. = 2.2

$Y_1 = 0.268\ X_1 - 3.548$ with $r = 0.72$, Std. Error of Est. = 6.7

(E) Treated Agricultural Watershed

$Y = 0.182\ X_1 - 2.274$ with $r = 0.8$, Std. Error of Est. = 3.5

$Y_1 = 0.292\ X_1 - 1.952$ with $r = 0.6$, Std. Error of Est. = 8.3

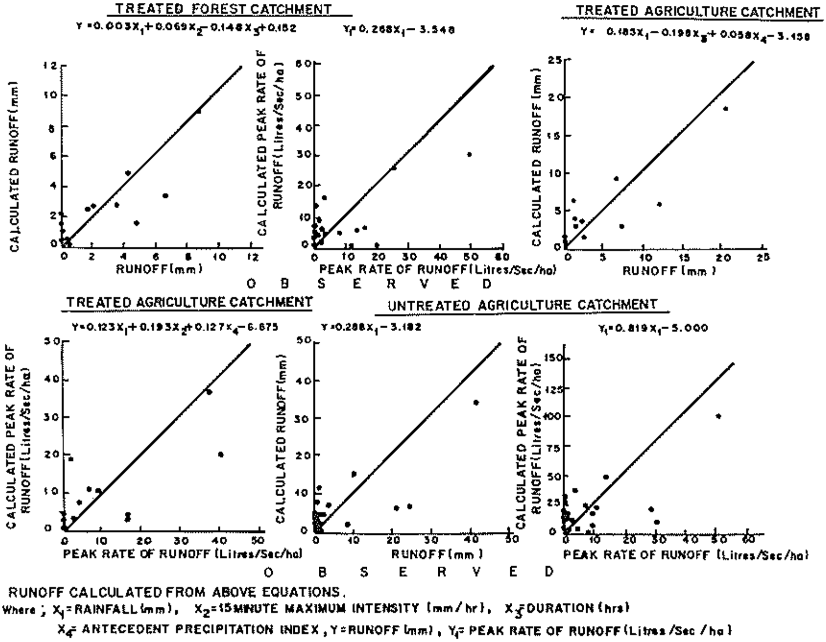

FIG. 3—Comparison of observed and calculated runoff using different equations with reference to 45° line of best fit.

(F) Untreated Agricultural Watershed

$Y = 0.288\ X_1 - 3.182$ with $r = 0.74$, Std. Error of Est. = 6.9

$Y_1 = 0.819\ X_1 - 5.000$ with $r = 0.7$, Std. Error of Est. = 23.7

where Y, Y_1 and X_1 are same as before.

For a given rainfall, higher runoff and peak rate of runoff will be produced from the untreated agricultural catchment, followed by the agricultural treated catchment, with lowest runoff and peak rate of runoff from the forest catchment. Observed and estimated runoff values from the catchments for different rainfall events are shown in Figure 3. The coefficient of determination between observed and estimated values for all cases is around 0.8.

Rainfall, runoff and sediment concentrations for each year are presented in Table 4. In spite of steep slopes (20 to 50%) and adverse soil surface conditions, the forest catchment recorded the lowest runoff as well as the lowest peak rate of runoff for each event during the years of the study. Average runoff from the treated forest catchment was 49% that of the treated watershed and 27% that of the untreated watershed. This is mainly due to creation of storage of 235 m^3 of water per ha through formation of contour trenches, increasing the opportunity for rainwater to soak in. Additional runoff was intercepted by the increased growth of natural grass, yielding 17 to 19 t/ha of green matter under

TABLE 4—Runoff and sediment yields from different catchments

Year	Annual rainfall (mm)	Runoff-producing rainfall (mm)	Runoff											
			Treated forest catchment				Treated agricultural catchment				Untreated agricultural catchment			
			Total runoff (mm)	% of annual rainfall	% of runoff producing rainfall	Sediment concentr (kg/m^3)	Total runoff (mm)	% of annual rainfall	% of runoff producing rainfall	Sediment concentr (kg/m^3)	Total runoff (mm)	% of annual rainfall	% of runoff producing rainfall	Sediment concentr (kg/m^3)
1987	669.8	316.1	14.92	2.23	4.72		35.72	5.33	11.30		— Not collected —			
1988	689.4	465.0	20.45	2.97	4.40		24.94	3.62	5.36		63.53	9.22	13.66	
1989	588.8	331.3	22.15	3.76	6.68	From 0.58 to 2.46	41.90	7.11	12.65	From 0.65 to 3.55	81.31	13.81	24.54	From 3 to 7.23
1990	523.4	199.2	9.06	1.73	4.55	From 3.6 to 5.75	32.66	6.24	16.39	From 5.54 to 7.23	42.23	8.07	21.21	From 9.23 to 16.57

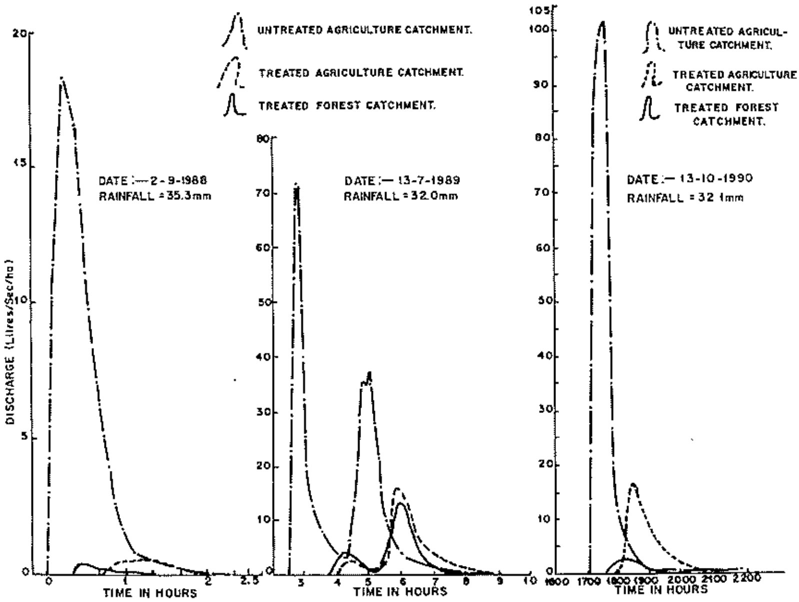

FIG. 4 - Runoff hydrographs as influenced by catchment treatments.

treated conditions against 1 t/ha during pre-treatment (Rama Mohan Rao et al, 1988). Sharda et al (1980) observed that formation of contour trenches reduced runoff from 171 mm to zero in a span of eight years and increased grass yield from 33 to 155 Q/ha. Similarly Rao et al (1982) reported that the runoff from an agricultural watershed was 15.1%, while it was only 6.8% of annual rainfall of 786 mm for a grass watershed with contour trenches. Runoff was reduced by 84% in a watershed treated with *bunds* and waterways, compared to an untreated watershed. This clearly demonstrates the effectiveness of conservation measures in reducing runoff from arable land as reported by Sastry and Dhruvanarayana (1984) and Tejwani (1979).

Sediment Concentration in Runoff

During the years of this study, sediment concentrations were found to be lowest in runoff from non-arable forested land (ranging from 0.58 to 5.75 kg/m^3), higher in runoff from the treated agricultural watershed (0.65 to 7.23 kg/m^3), and highest in runoff from untreated agricultural lands (3.00 to 16.57 kg/m^3). These results underline the necessity for organising effective conservation programmes in catchments to arrest soil erosion.

Hydrograph Analysis

Hydrographs obtained from three catchments for similar rain storms are presented in Figure 4. Peak, recession and relative recession times for these hydrographs are presented in Table 5. The lowest relative recession time (Recession time/Peak), indicating a rapid rise and fall of flow was in hydrographs from

TABLE 5—Peak, recession and relative recession time for three typical hydrographs

Date	Hydrograph from treated forest catchment			Hydrograph from treated agricultural catchment			Hydrograph from untreated agricultural catchment		
	Peak (l/sec/ha)	Recession time (hrs)	Relative recession time	Peak (l/sec/ha)	Recession time (hrs)	Relative recession time	Peak (l/sec/ha)	Recession time (hrs)	Relative recession time
02.09.88	0.31	1.37	4.42*	0.47	1.00	2.13*	18.35	2.13	0.12*
13.07.89	13.83	3.67	0.27*	16.8	3.42	0.2*	71.84	5.83	0.08*
13.10.90	2.47	3.0	1.22*	16.71	4.86	0.29*	101.76	2.42	0.02*

* The relative recession time (the ratio of recession time to peak)

TABLE 6—Water balance of three watersheds (mm)

Year	Precipitation (P)	Runoff (R)			Evapotranspiration (E_T)			Ground water recharge (S_G)		
		U.T.A.C.	T.A.C.	T.F.C.	U.T.A.C.	T.A.C.	T.F.C.	U.T.A.C.	T.A.C.	T.F.C.
1987	669.8	57.6	35.7	14.9	556.0	573.8	576.6	56.3	60.3	78.3
1988	689.4	63.5	24.9	20.5	557.1	559.8	560.3	68.8	104.6	108.7
1989	588.8	81.3	41.9	22.2	507.5	546.9	566.7	Negligible	Negligible	Negligible
1990	523.4	41.4	32.7	10.7	482.0	490.7	512.8	Negligible	Negligible	Negligible
Average	617.9	61.0	33.8	17.1	525.7	542.8	554.1	31.3	41.2	46.8

U.T.A.C. = Untreated Agricultural Catchment, T.A.C. = Treated Agricultural Catchment
T.F.C. = Treated Forest Catchment

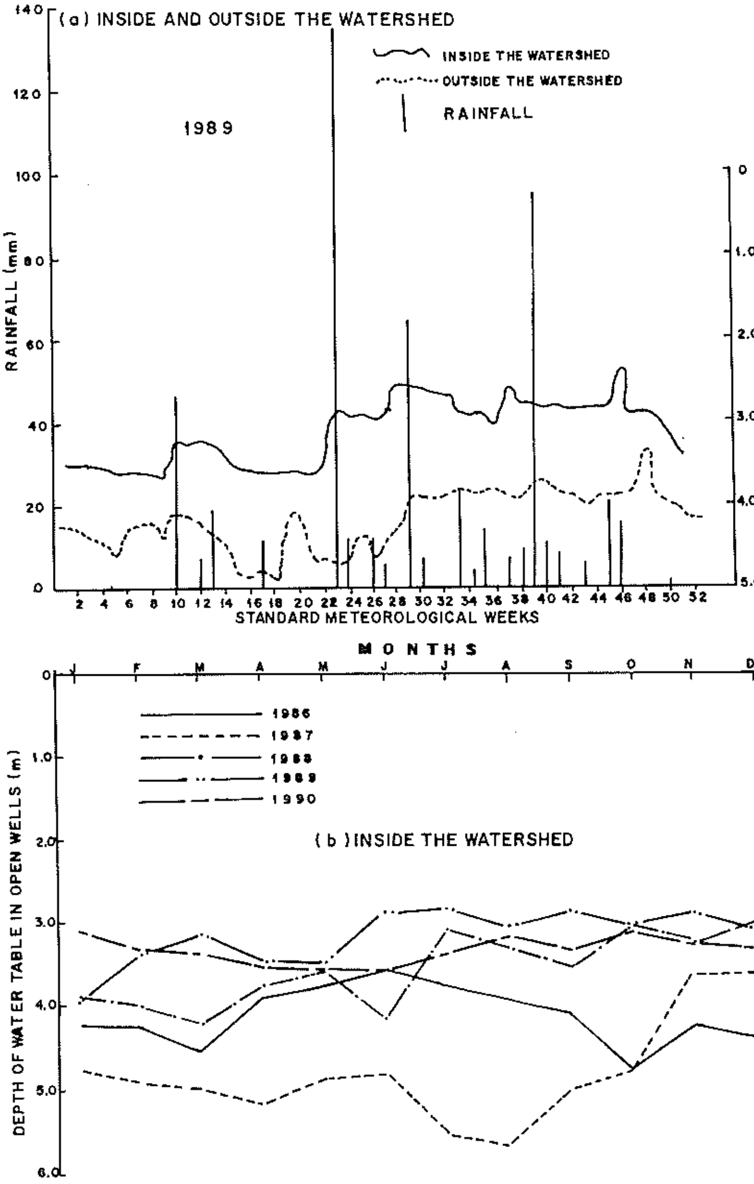

FIG. 5—Fluctuations of water levels in the open wells.

TABLE 7—Ground water development programme for efficient utilisation of wells in the watershed

Period	Year	Area (ha) irrigated by 47 wells	% of increase in irrigated crop area over pre-project period
Pre-project	1984–85	88.52	—
Post-project	1985–86	117.21	32.4
	1986–87	116.64	31.8
	1987–88	98.43	11.2
	1988–89	125.50	41.8
	1989–90	129.76	46.6
	1990–91	136.68	54.4

the untreated watershed, followed by treated agricultural and treated forest watersheds. The initiation of runoff was earliest in the untreated watershed for all storms, whereas runoff was delayed by 20 minutes to 2 hours in the treated agricultural and forest watersheds respectively. This indicates that soil and water conservation measures not only reduce runoff and peak rate of runoff, but also increase the relative recession time, allowing more opportunity for infiltration of rain water and groundwater recharge, and thereby moderating floods.

Water Balance Analysis

Water balance for the three catchments was computed and the results are presented in Table 6. Groundwater recharges of 46.8, 41.2 and 31.3 mm of rainfall, averaged over 4 years, occurred under treated forest, treated agricultural and untreated agricultural watersheds respectively. These results suggest increased ground water recharge due to the soil and water conservation programmes.

Water levels in the wells within the treated area, and in one well in the untreated area were monitored, (Fig. 5A), along with changes in the water levels in wells with time after conservation treatment in the watershed (Fig. 5B).

Figure 5 shows monthly fluctuations in water table of wells (average of 47 wells) in the watershed from 1986 to 1990 along with the weekly fluctuations of water table for both inside and outside the watershed for the year 1989.

Figure 5 reveals rises of 0.5 to 1.07 m in the water table in the wells within the treated area when compared to that of the well located outside the watershed, in spite of irrigating additional crop areas. Further, observations on depth to water table inside the watershed during the five years 1986 to 1990 reveal that, depending upon rainfall, the water table level rose about 0.22 m per year during the dry season (September to March) indicating long-term increases in ground water levels due to conservation measures. The figure of 0.22 m per year is the difference between independent measurements made in 1986 and 1990 of the September to March average water levels. Increased water has allowed larger crop areas to be irrigated by each well. The 47 wells inside the watershed dating from the pre-project period registered a 36.4% increase in crop area on average, when compared to the pre-project period (Table 7), bringing an additional production of 33 t/year of groundnut.

CONCLUSION

Soil and water conservation measures considerably reduced runoff, peak rate of runoff and sediment concentration in runoff, with minimum values from treated forest followed by treated agricultural and the maximum values from untreated agricultural watersheds. As a result of conservation measures in the catchment, there was a considerable rise in water level in open wells inside the watershed, which helped to increase the area which could be irrigated by the wells, and thereby increased production. This study shows a definite and positive effect of integrated development on the hydrological behaviour of a watershed in which management of rain water is based on scientific principles of soil and water conservation.

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