TR(BR)-12/97-98

Study of Impact of Wet and Dry Spells in Rainfall Records on the Water Availability Estimates

आपो हि ष्ठा मयोभुवः

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (U.P.) INDIA

1997-98

CONTENTS

List of Figures

List of Tables

Abstract

This report examines the effect of periodicity in the rainfall records on the water availability of a basin. Based on the rainfall-runoff record of a shorter period, runoff series for a longer period is developed using a water balance model. Percent deviation in water availability estimations computed using a short term wet or dry record to that of complete record is examined. Effect of length of time series on the water availability estimates is also studied.

Results indicate that a minimum of seven and half years of record is needed for estimation of water availability on a monthly scale for Damanganga basin and the effect of wet and dry spells play a crucial role in the determination of water availability.

1. INTRODUCTION

Water is the most precious gift of the nature, the most crucial for sustaining life is required for almost all types of activities. The development, conservation and use of water, therefore, forms one of the main elements in the country's development planning. Considering the fact that the available water resources of the country are now under stress with the increasing future demands, optimum and efficient utilization of available water resources based on scientific knowledge is becoming essential.

For planning and design of a water resource project, basic requirement is the availability of sufficient length of rainfall and/or runoff records for the estimation of availability of water for that basin. Generally, for most of the basins in the country, the available runoff data is either of short duration or has gaps due to missing data. Based on limited data, hydrologists have proposed equations relating monthly runoff to factors such as monthly rainfall and monthly average temperature (Khosla, 1949, Murry, 1971). These equations and other similar equations developed elsewhere, such as that proposed by Mimikou & Rao (1983), have been used for planning purposes in cases where no other information is available. Now, with the availability of more information, it has been observed that the results obtained by the use of these equations, produce large errors.

For a water resource assessment point of view, the primary objective of modelling is frequently to generate a long representative time series of streamflows from which a river basin project can be designed. The longer time series available from different sites within the similar climatologic regions are rarely coincident in time and may represent different sequences of dry and wet climatic conditions. The shorter length of data apart from other problems, always faces the problem of true representation of periodicity in time series viz. the representation of wet and dry spells. In the absence of availability of sufficient length of recorded runoff series, the best suited alternative is to develop a suitable rainfall-runoff relationship for the basin and then to generate the long term runoff series based on available rainfall series, particularly when the principal aim is to decide the feasibility and storage requirement of a water resources project. For many water resource estimation purposes, a monthly time-step model with relatively low spatial structure may be adequate (Hughes, 1995). In India as well as in other countries (Hughes and Smakhtin, 1996) monthly time series of runoff is often used as a basis for water resource development and management.

As the dimensions or size of a water resource project is based on the reliability of water flow at the site at different times of the year, therefore water availability is the lifeline of any irrigation or multipurpose project. The success of a project depends on how accurate has been the estimation of total quantity of water available and its variability. Proper estimation of water availability is therefore very essential. The water availability should be based for an irrigation project on 75%, for power projects on 90%, and for drinking water supply on 100%. Reliability can be estimated from the streamflow record, the characteristics of which can be depicted by flow duration curve. The flow duration curves have frequently been advocated for the use in hydrologic time series studies such as hydropower, water supply, and irrigation planning, design and management

In the present report, effect of wet and dry climatic conditions on the water availability of Damanganga basin are examined on monthly time scale. In doing so, first a suitable rainfall-runoff relationship for the basin is developed and then based on available rainfall records, long term runoff series is obtained. The recorded rainfall series and the modelled runoff series are examined further for studying the effect of record length and wet and dry spells on the water availability of the basin.

2. STUDY AREA AND DATA USED

India is divided into 11 agroclimatic zones based upon climatological characteristics. The focus basin of the present study is Damanganga basin located in central India. The selection of this basins for the present study was done because the required long term rainfall and other input data for the basin were readily available.

2.1 Damanganga Basin

The catchment area of river Damanganga can be physiographically divided into five units namely, hill slopes, hill plateaus, upper and lower foot slopes, valley plains and local depressions, river and stream. The soils of the basin can broadly be grouped into the groups viz. Black soils, red soils and Mixed soils. The black soils are distributed over the entire basin. The red soils are found in Thane and Nasik districts of the Maharashtra. Mixed soils are found in parts of the Thane and the Nasik districts of the Maharashtra. The average forest area is about 41% and the agricultural area is about 47% of the total geographical area of the basin. Agriculture is the main occupation of the people in the basin. The general description of Damanganga basin is given in Table 1.

2.2 Data Used

Fig. 1 gives the index map of the basin showing the locations of gauge discharge and raingauge stations. There are twelve raingauge stations located in and around the basin. The monthly rainfall record for the period from 1901 to 1984 was available while runoff record from the year 1972 to 1983 was available. The use of a conceptual model, normally requires rainfall, runoff and temperature or evapotranspiration data, along with some watershed characteristics. As no meteorological data for the complete period, for the watershed was available, for sake of simplicity, normal evapotranspiration values as derived by India Meteorological Department for the region, have been used.

Table 1 : General description of study area

Latitude	19° 45' to 20° 20'
Longitude	72° 40' to 73° 40'
Elevation	950 m to 0 m
Normal annual rainfall	2212 mm
Normal annual runoff	1427 mm
Data availability	
Rainfall	1901-84
Runoff	1974-83
Area	2261 sq km
Region	Humid
Location	Central India

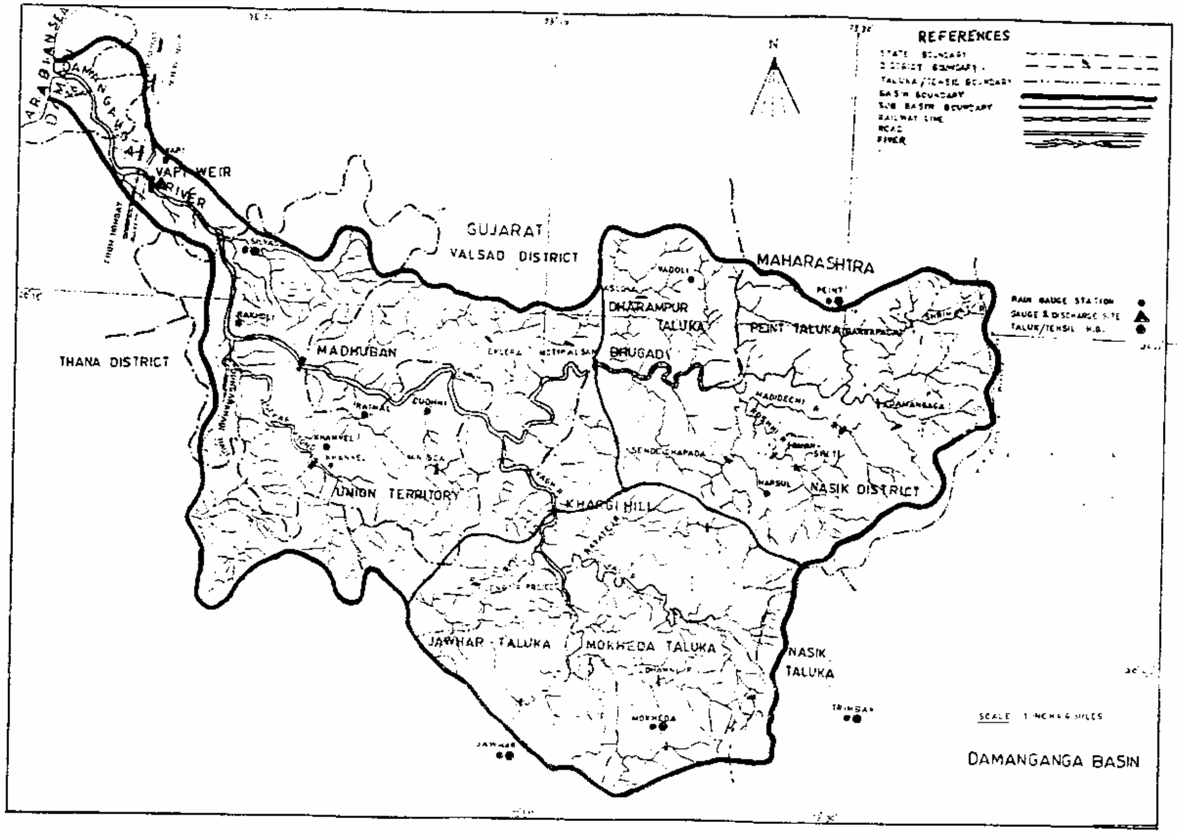


Figure 1: Index map showing locations of raingauge and gauge discharge stations for Damanganga basin

3. METHODOLOGY

First phase of the study involves the calibration of a monthly rainfall-runoff model using basin average rainfall and runoff records for the period 1972-83 and then computation of runoff for the complete period 1901 to 1984 based on calibrated model and basin average rainfall record. Some common models based on simple statistical equations to some complicated conceptual structures have been selected and applied and their results compared. Based on the results, the best model is finally selected for further analysis.

Second phase involves the development of flow duration curves based on following criteria and comparison of water availability at different dependabilities and also for wet and dry spells. To compute the water availability, the available record is arranged in descending order and then serial number of an item corresponding to a particular dependability is computed from the total number of record available i.e. if 39 observations are available then 75% dependable item number from top would be (39+1)x75/100 = 30. Thus the 30th record from the top would be 75% dependable flow.

a. Total rainfall record from 1901 to 1984 is plotted and it is divided into wet and dry segments. Water availability for each segment and for the whole period is computed and compared with the whole period using the modelled runoff records.

b. A series of first 30 months of runoff record, from the modelled monthly runoff series is considered and water availability at different dependabilities for the series is computed. Now leaving the first month, next 30 months are picked up and water availability for this new series is computed. The procedure is repeated for the complete runoff series. Thus if 84 years of record is available, then total monthly records would be 1008 and total 1008-30 = 978 series could be constructed. Same procedure is repeated considering record length of 60, 90, 120, 150, 180, 210 and 240 months. For each series, within a record length, mean monthly rainfall is computed and for a particular dependability, a plot of mean monthly rainfall and corresponding dependable flow is obtained. A best fit line for this plot is obtained which gives the relationship between mean monthly rainfall and dependable flow at a particular dependability considering a fixed record length. Now considering the complete record length, mean monthly rainfall and dependable flow at different percent of time is computed. It is assumed that these mean monthly rainfall and dependable flows as obtained by using the complete record are true representative values for the basin. Considering this mean monthly rainfall, and using the equation of best fit line, dependable flows for different sets are computed and are compared with the true representative dependable flows for the basin.

These two exercises helped in finding out the effect of record length and wet and dry periods on the water availability of the basin.

3.1 Computation of basin average (areal mean) monthly Rainfall

For the present study, areal mean rainfall for the basin is computed using Theissen Polygon method. The availability of number of raingauges varies from time to time. Details of number of raingauges available, their period of availability and Theissen weights are given in Table 2. The table depicts that from 1901 to 1954 there were three raingauges only and from 1955 onwards number of raingauges increases and finally the number reaches to twelve. Considering the availability of total number of raingauge records at a particular time, areal mean is computed. To consider the effect of variation of number of raingauges i.e. effect of spatial variation in rainfall on mean rainfall as a result of inclusion of a raingauge in the basin, areal mean rainfall for the complete period is computed using the rainfall values from three raingauges which are in existence since 1901 and it is plotted against the mean rainfall as computed using all the existing raingauges (Fig. 2). Cumulative values of mean monthly rainfall as obtained by using rainfall at only three stations and at all the stations as available from time to time is given in Fig. 3. From Fig. 2 it appears that there is some variation in the mean monthly rainfall values but when cumulative values are plotted almost a straight line is obtained (Fig. 3).

Table 2: Thessien weights assigned to different stations during different periods

Period	Stations and their Thessien weights											
	Peint	Mokh ada	Trimb ak	Jawahar	Vapi	Silvasa	Khanvel	Dudh ani	Rakholi	Raima l	Vadoli	Harsul	Sum
01-54	0.481	0.481	0.039										1
55-61	0.435	0.223	0.039	0.304									1
62-63	0.375	0.223	0.039	0.191	0.17								1
64-65	0.339	0.223	0.039	0.127	0	0.265							1
66	0.261	0.163	0.039	0.06	0	0.049	0.138	0.283					1
67-72	0.159	0.148	0.039	0.060	0.007	0.035	0.099	0.219	0.032	0.028	0.173		1
73-82	0.113	0.113	0.018	0.06	0	0.035	0.099	0.21	0.032	0.03	0.106	0.184	1
83	0.113	0.113	0.018	0.06	0	0.049	0.117	0.205	0.00	0.028	0.106	0.184	1
84	0.113	0.155	0.018	0	0	0.049	0.127	0.212	0	0.028	0.106	0.184	1

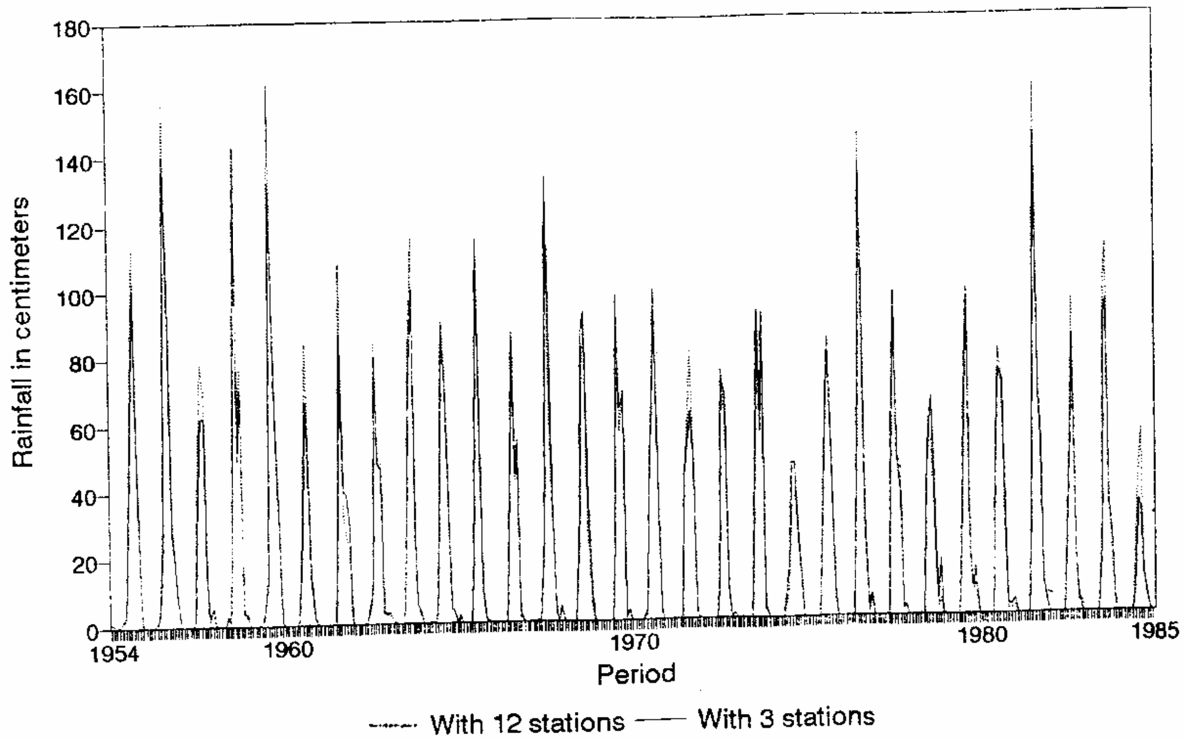


Figure 2: Plot of mean monthly rainfall considering 3 and 12 stations

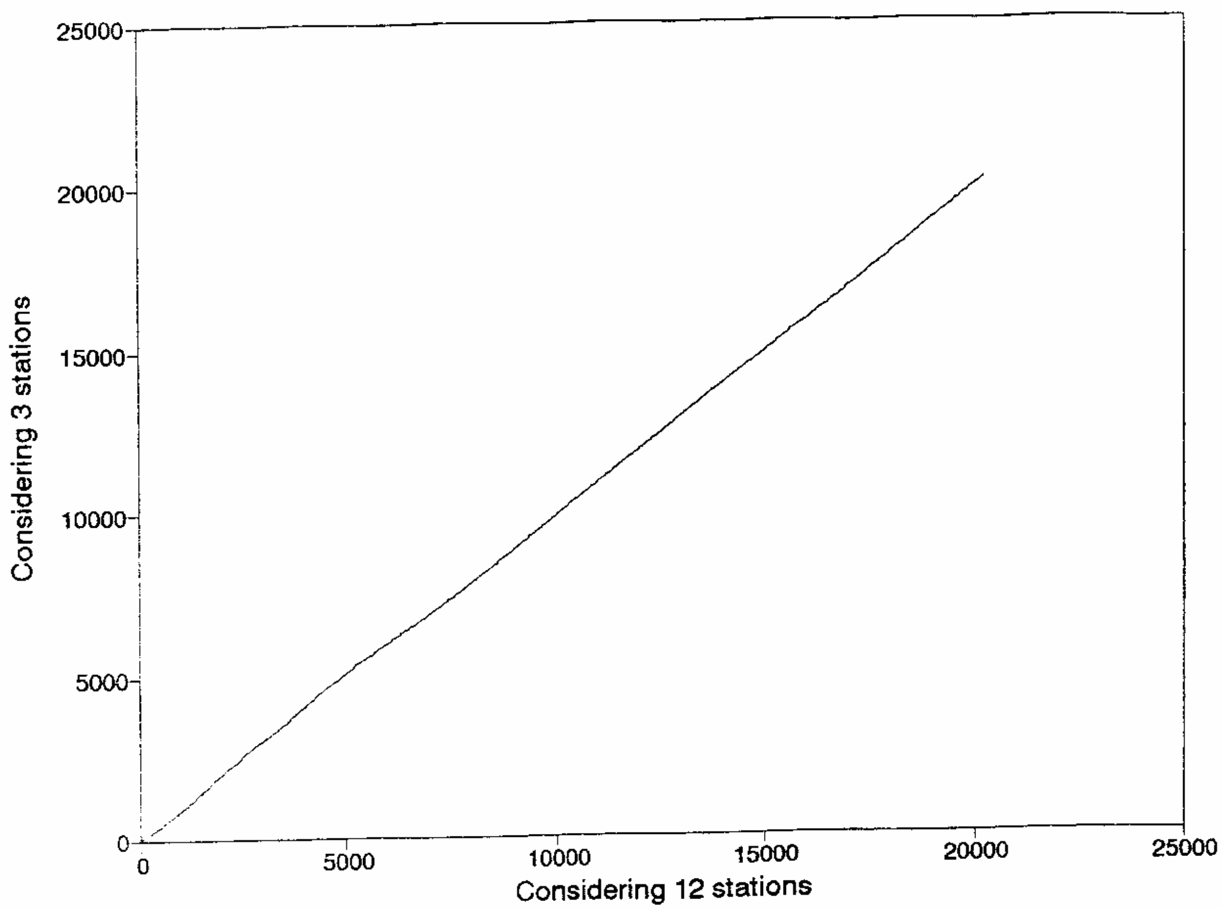


Figure 3: Cumulative plot of mean monthly rainfall considering 3 and 12 stations

Therefore, further analysis is performed assuming that there is not much effect of networking of raingauges on the basin average rainfall values. However, this aspect needs further examination which could not be included here.

3.2 Rainfall - Runoff Modelling

Use of rainfall-runoff modelling has been started since 10's or 20's whereas hydrologic simulations models of watershed based on physical and mathematical concepts have been developed since the beginning of the 1960's. Recent development in computers and analysis techniques have led to significant developments and application of mathematical and conceptual models in hydrology so as to help solving a variety of hydrological problems. For water resources projects in regions where the number of rainy days in a rainy season is more, the hourly and even daily time steps may be replaced by a monthly time step without loosing significantly the accuracy of the predicted model output. Alternatively, where raingauges are limited, the monthly lumped models can even produce better results as compared to other distributed models operating on smaller time scales. Because of these favours, these models are increasingly used in hydrology for various purposes. The water balance models are very popular and are widely used for the assessment of surface runoff. These are also used for generating arbitrarily long runoff series which can be used for design of a water resource project.

In the present study, three water balance models and a statistical model are used to develop the rainfall-runoff relationship for the Damanganga basin and their performance is evaluated For the basin under study, the runoff record is available for the periods 1972-83 only while rainfall record is available for the period 1901 to 1984. A suitable rainfall-runoff relationship based on rainfall and runoff records for the period 1972-83 is developed. As the study involves the computation of water availability, the performance of these models is compared on the basis of flow duration curves only. Out of four models selected, three viz. M1, M2 and M4 are based on water balance approach while fourth one i.e. M3 is based on statistics. Number of parameters used in these models are given in Table 3 while flow chart of these models are given in Figs. 4 to 6.

Table 3 : No of parameters used in different models.

Model Name	No. of Parameters used	Model Name	No. of Parameter used
M1	3	M2	2
M3	5	M4	5

3.2.1 M1 Model

This model operates on three parameters. First parameter SMAX, relates to moisture holding capacity of the soil. Second parameter describes the threshold value of rainfall such that rainfall greater than this value will appear directly as runoff, referred here as Fast surface runoff (FSR). It is worked out on the basis of soil moisture deficiency and SMAX. Quick surface runoff (QSR) is controlled by the average soil moisture deficit. Similarly, evapotranspiration (AE) from the catchment is also governed by potential evapotranspiration, average soil moisture and a parameter defining threshold value of soil moisture for evapotranspiration. If infiltrated water is in excess of SMAX, deep percolation occurs. Delayed runoff or interflow (DSR) occurs if percolated water is in excess of a limit SMAX2. Fig. 4 describes the structure of the model and equations used.

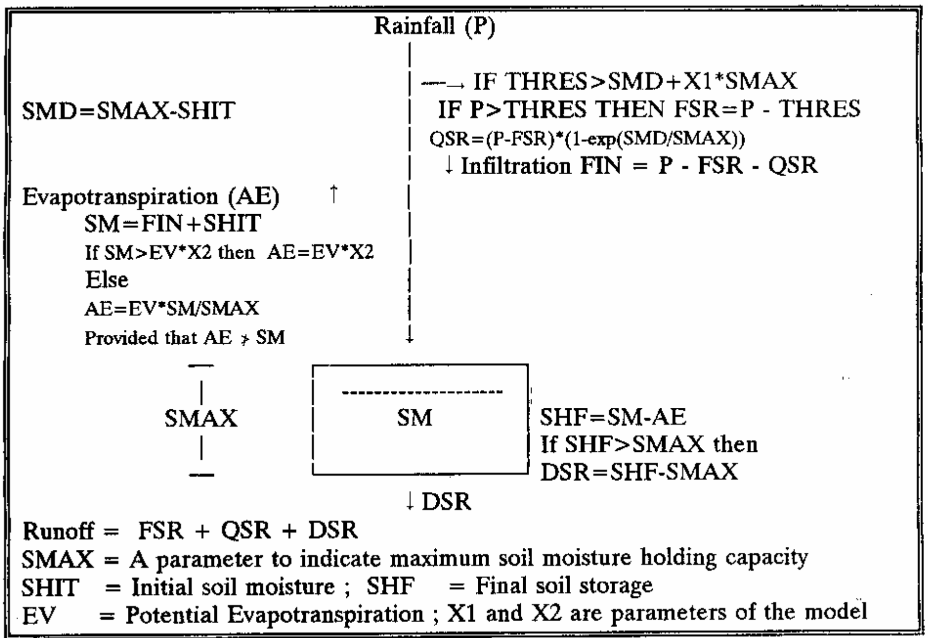


Fig. 4 : Structure and schematic representation of M1 model.

3.2.2 M2 Model

This model considers only soil storage. A parameter SMAX is used to represent the soil moisture holding capacity of the soil storage while one additional parameter is used to define the threshold value for FSR. Fast surface runoff (FSR) is the portion of rainfall in excess of the soil moisture deficit of the soil storage. Quick surface runoff (QSR) depends on the average soil moisture condition of the soil storage. It follows an exponential function. Evaporation from the soil storage is governed by the average soil moisture available in the soil storage.

Structure of M2 model and equations used are given in Fig. 5.

```
                                   Rainfall (P)
                                        |
SMD= SMAX-SHIT                          | —→ FSR=P-THRES(If P>THRES)
 THRES=SMD+X1*SMAX                      | —→ QSR=P*(1.-EXP(-SMAV/SMAX))
Evapotranspiration (AE) ↑               |       SMAV= Average soil moisture
    If SM>EV, AE = EV                   |               during the month
Else, AE = EV*SMAV/SMAX                 |    ↓ Infiltration FIN = P - FSR - QSR
                                        ↓
              —         ┌──────────────────┐
              |         |                  |
            SMAX        | SM= SHIT+FIN     | ——→ DSR
              |         |                  | If SM-AE>SMAX,
              —         └──────────────────┘ DSR=SM-AE-SMAX
Runoff = FSR + QSR + DSR

SMAX = A parameter to indicate maximum soil moisture holding capacity.
SHIT= Initial soil moisture.
EV= Potential Evapotranspiration.
X1 = A parameter of the model.
```

Fig. 5 : Structure and schematic representation of M2 model.

3.2.3 M3 Model

Most simple statistical structure is to represent the runoff as a linear fraction of rainfall. In the STAT model runoff of a particular month is considered as a fraction of the rainfall. Thus for each month one parameter is required. In the present study, five monsoon months from June to October have been considered.

The governing equation of the model takes the form:

$$Q_j = X_j * P_j \qquad (1)$$

Here Q, P, X are runoff, rainfall and runoff coefficient of the jth month respectively.

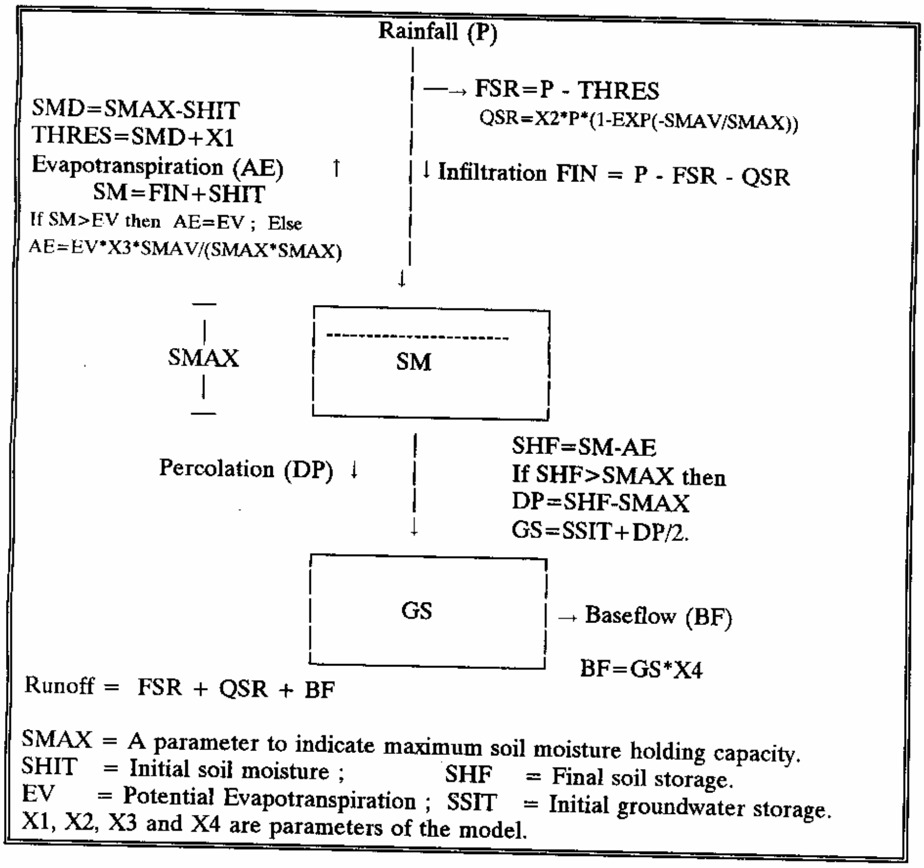


Fig. 6 : Structure and schematic representation of M4 model.

3.2.4 M4 Model

This model consists of 5 parameters. Two storages namely soil and ground water storage, are considered. First parameter SMAX relates to moisture holding capacity of the soil. Second parameter THRES defines the threshold value of rainfall such that rainfall greater than this value will appear directly as runoff, referred here as Fast surface runoff

(FSR). Third parameter decides the portion of the remaining rainfall which will appear as surface runoff (QSR) depending upon the average soil moisture available in the soil storage. Fourth parameter SMAX1 decides the evapotranspiration (AE) occurring from the soil storage. Fifth parameter is a constant which governs baseflow (BF) from the groundwater storage. Structure of the model and governing equations are given in Fig.6.

Recorded yearly flows for the period 1972-83, yearly mean rainfall and modelled runoff values as obtained by using these four models are given in Fig. 7, whereas flow duration curves of recorded and modelled monthly runoff values are given in Fig. 8.

3.3 Development of flow duration curves

3.2.1 Criterion a

Yearly rainfall during the period from 1901 to 1984 is plotted and 5, 10, 15 and 20 years moving averages are computed as shown in Fig. 9. Based on this plot, total record length can be broadly divided into three periods. First period from 1901 to 1929 indicates low rainfall period, second period from 1930 to 1959 indicates wet period and the third period from 1960 to 1984 again indicates dry period. Mean monthly rainfall of these periods and complete period (from 1901 to 1984) is computed as 185, 228, 187 and 201 mm respectively. Flow duration curves for these different time periods for monthly values and for yearly values are plotted and shown in Fig. 10 and 11 respectively. Details of mean rainfall, runoff and dependable flows for these periods, on monthly and yearly basis are given in Table 4.

3.2.2 Criterion b

Considering a set of 30 consecutive months, out of 1008 months of record available, 978 series each of length equal to 30 months are constructed. For each series, its mean monthly rainfall and dependable flows at 10, 20, 30, 40, 50, 60, 70 and 80 percents of time are computed. Average of dependable flows for all these series i.e. for this set, at a particular dependability and mean rainfall value for this set are also computed. Now, for all these series, at a particular dependability, mean monthly rainfall and dependable flow values are plotted and a best fit line is drawn through these points. Similar exercise is repeated for all sets of 60, 90, 120, 150, 180, 210 and 240 consecutive months. Values of slope, intercept and R^2 for these best fit lines are given in Table 5. Values of average dependable flows for each set at different percent of time are given in Table 6. Values of average rainfall in mm for each set computed are given below.

No. of months in each set	30	60	90	120	150	180	210	240
Mean rainfall in mm	208.6	205.4	205.1	205.1	205.6	205.9	206.2	206.6

Some sample plots for 10, 20, 30 and 40 percent dependable flows and considering 60 consecutive months are given in Fig. 12 whereas for 50 and 70 percent dependable flows, these plots are given in Figs. 13-16.

Table 4: Mean rainfall, runoff and dependable flows in mm for wet, dry and complete periods.

Period	Mean rainfall in mm	Mean runoff in mm	Dependability in percent								
			10	20	30	40	50	60	70	80	90
On monthly basis											
1901-29	185	113	321	113	54	28	15.5	8.51	4.48	2.11	0.75
1930-59	228	153	420	152	73	39	22	12	6.44	3.09	1.12
1960-84	187	114	328	118	57	30.3	16.8	9.37	5	2.4	0.86
1901-84	201	127	354	127	61	32	18	10	5.28	2.52	0.91
On yearly basis											
1901-29	2216	1350	1975	1713	1546	1417	1306	1203	1103	995	863
1930-59	2730	1832	2441	2174	2000	1863	1743	1631	1518	1397	1244
1960-84	2238	1369	2123	1803	1603	1450	1320	1202	1087	967	821
1901-84	2406	1528	2276	1952	1747	1589	1455	1332	1212	1085	930

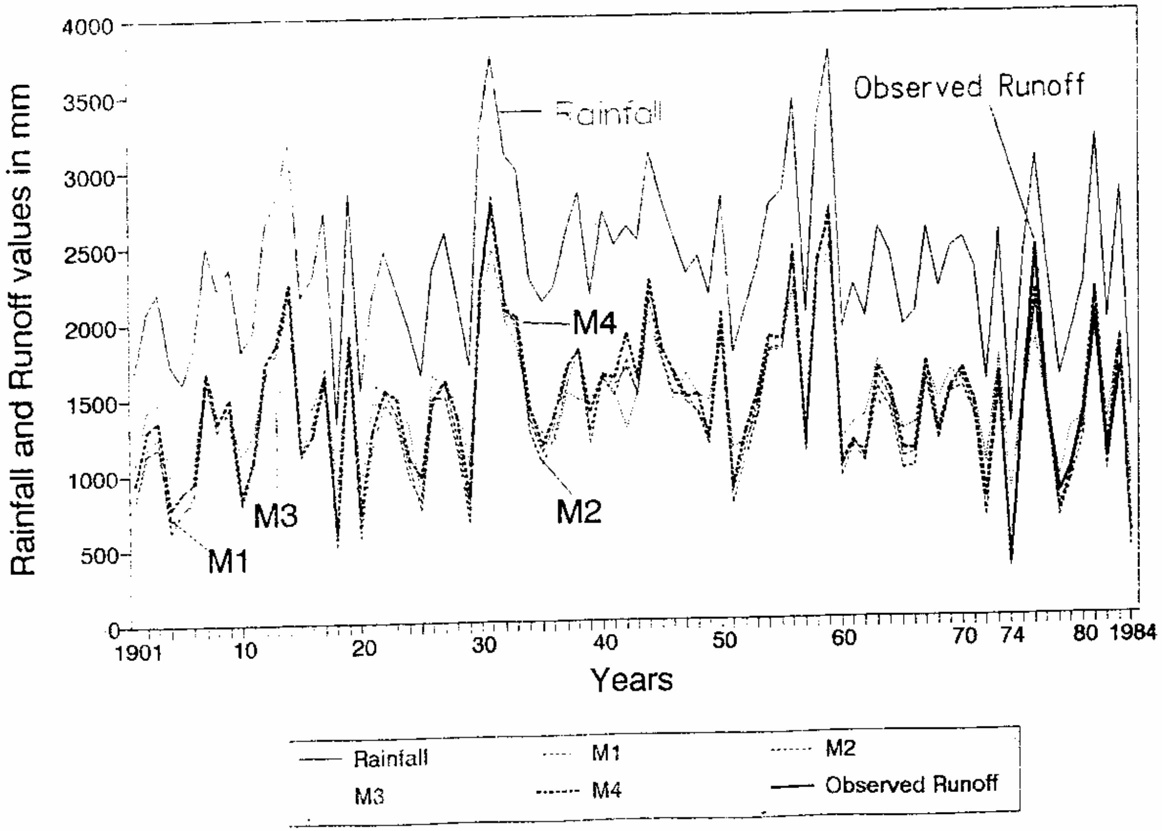


Figure 7: Recorded and modelled yearly runoff series

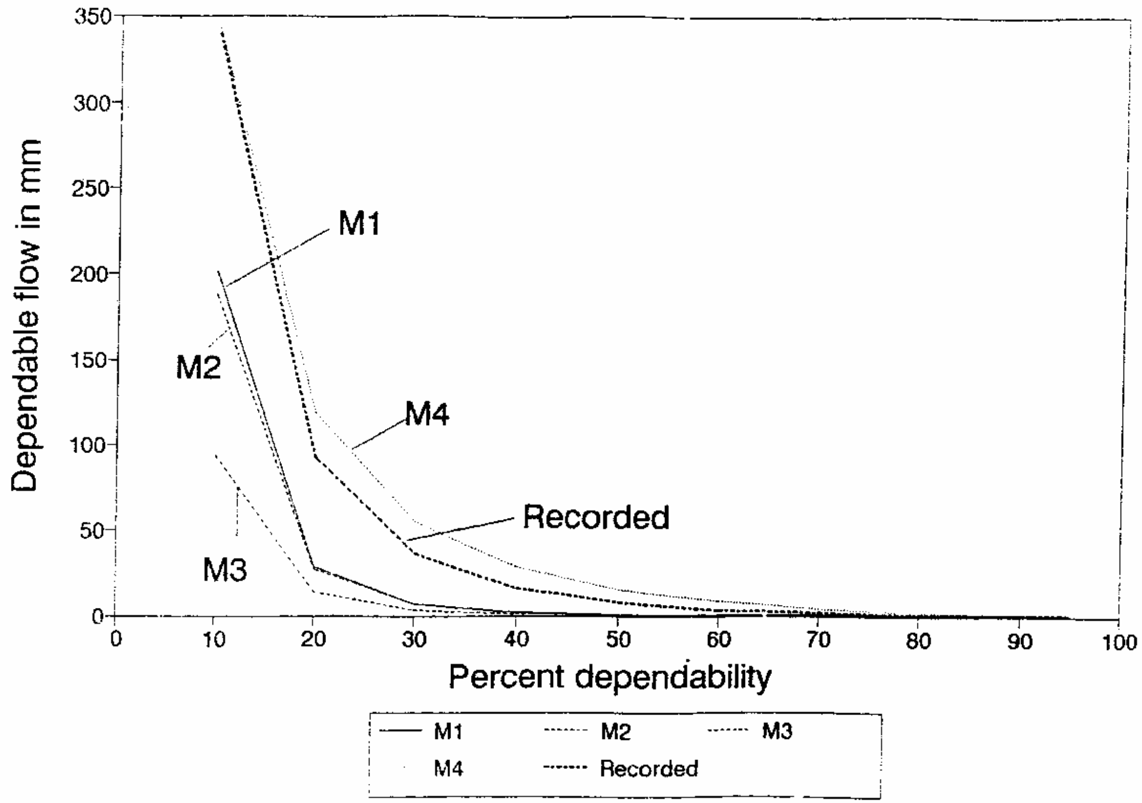


Figure 8: Flow duration curves of recorded and modelled monthly runoff series

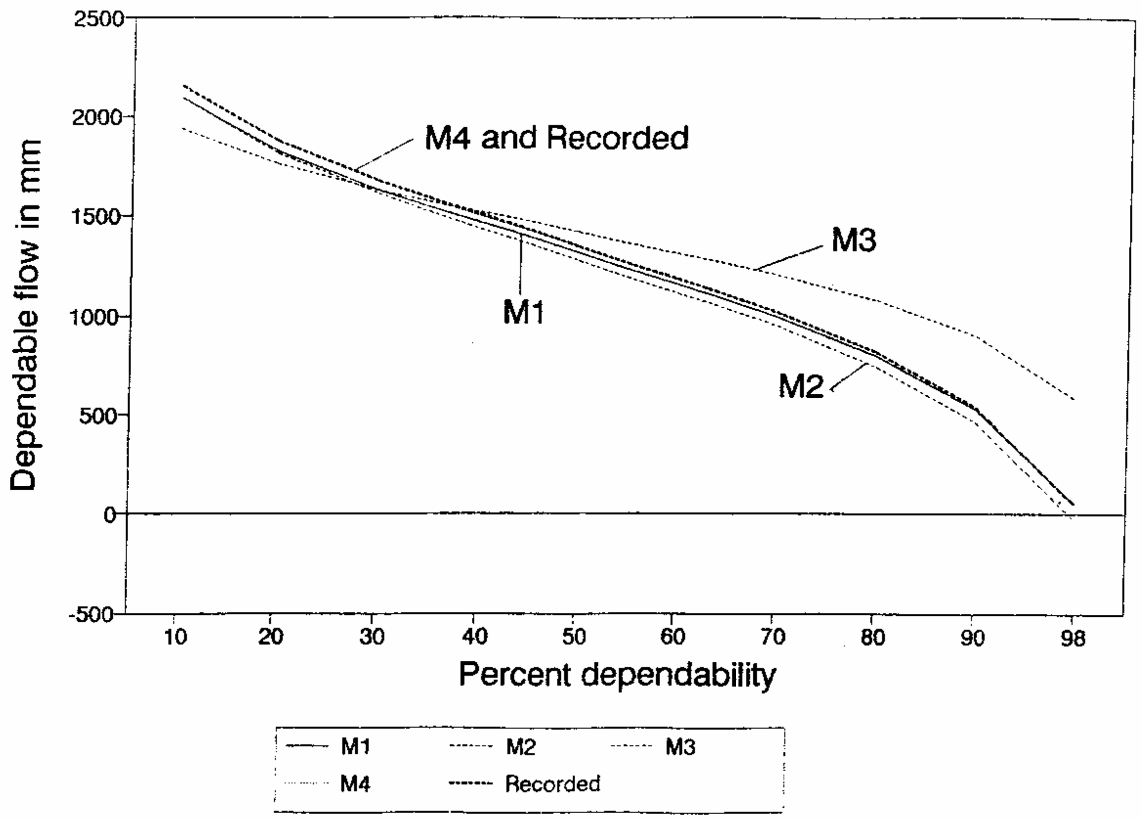


Figure 9: **Flow duration curves of recorded and modelled yearly runoff series**

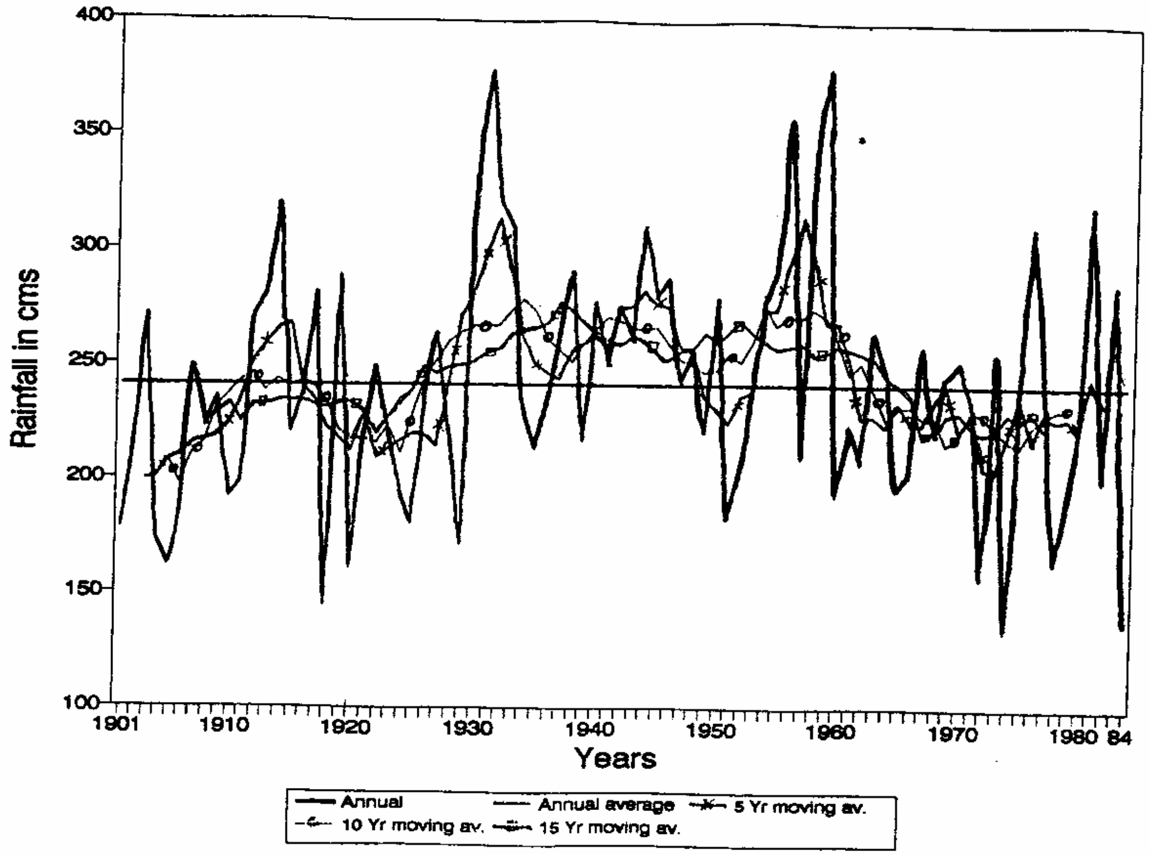


Figure 10: Yearly rainfall and moving averages for the period 1901-84

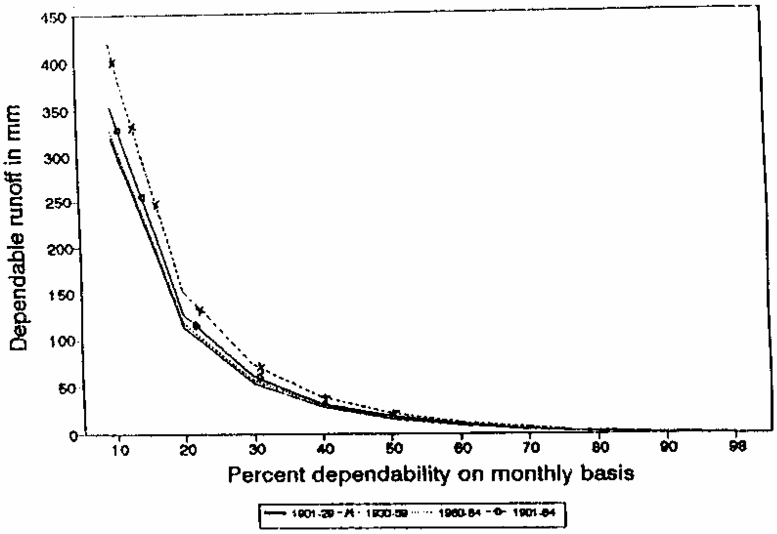


Figure 11: Flow duration curves of wet and dry periods for monthly flows

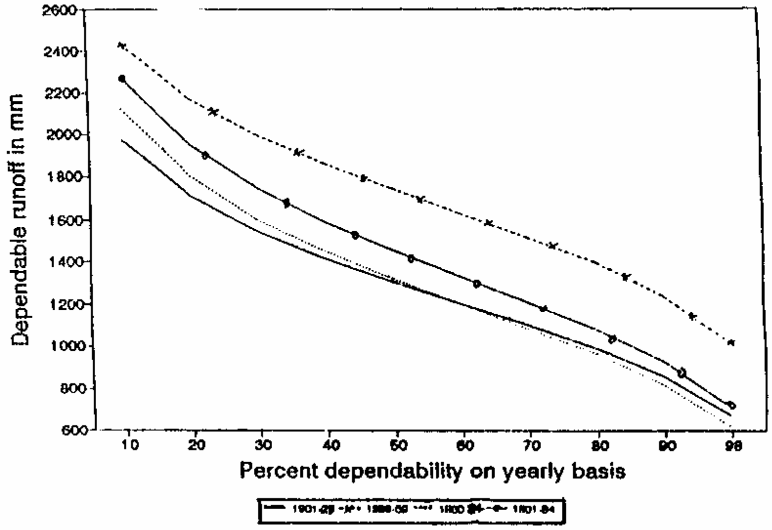


Figure 12: Flow duration curves of wet and dry periods for yealry flows

Table 5: Slope, Intercept and R^2 details of the best fit lines for different sets of consecutive months and dependabilities.

Percent dependability	Number of consecutive months considered											
	30			60			90			120		
	slope	intercept	R^2	slope	intercept	R^2	slope	intercept	R^2	slope	intercept	R^2
10	2.754	-163.6	0.7	2.179	-65.77	0.79	2.358	-107.1	0.76	2.181	-74.39	0.82
20	0.913	-47.11	0.64	0.827	-35.08	0.76	0.865	-43.66	0.73	0.850	-41.32	0.8
30	0.412	-18.79	0.57	0.410	-20.52	0.72	0.420	-22.59	0.69	0.429	-24.64	0.77
40	0.210	-8.410	0.5	0.224	-12.57	0.67	0.226	-12.79	0.64	0.239	-15.30	0.74
50	0.112	-3.877	0.43	0.128	-7.810	0.62	0.127	-7.490	0.6	0.138	-9.611	0
60	0.059	-1.730	0.36	0.073	-6.780	0.57	0.071	-4.373	0.55	0.079	-5.944	0.67
70	0.030	-0.690	0.29	0.040	-2.790	0.53	0.039	-2.448	0.51	0.044	-3.507	0.64
80	0.014	-0.200	0.23	0.020	-1.468	0.48	0.019	-1.235	0.46	0.022	-1.866	0.6

Percent dependability	Number of consecutive months considered											
	150			180			210			240		
	slope	intercept	R^2	slope	intercept	R^2	slope	intercept	R^2	slope	intercept	R^2
10	2.295	-98.84	0.78	2.154	-70.96	0.83	2.240	-89.58	0.81	2.145	-71.06	0.85
20	0.869	-45.10	0.77	0.840	-39.36	0.86	0.857	-42.98	0.83	0.850	-41.70	0.89
30	0.430	-24.77	0.75	0.424	-23.52	0.85	0.428	-24.21	0.82	0.433	-25.43	0.89
40	0.236	-14.61	0.71	0.236	-14.64	0.82	0.236	-14.53	0.8	0.243	-16.02	0.88
50	0.134	-8.843	0.68	0.136	-9.215	0.8	0.135	-8.924	0.77	0.141	-10.17	0.86
60	0.076	-5.303	0.64	0.079	-5.718	0.77	0.077	-5.424	0.74	0.082	-6.357	0.84
70	0.042	-3.045	0.6	0.043	-3.377	0.74	0.042	-3.150	0.71	0.046	-3.780	0.81
80	0.021	-1.577	0.56	0.022	-1.801	0.7	0.021	-1.649	0.67	0.023	-2.032	0.78

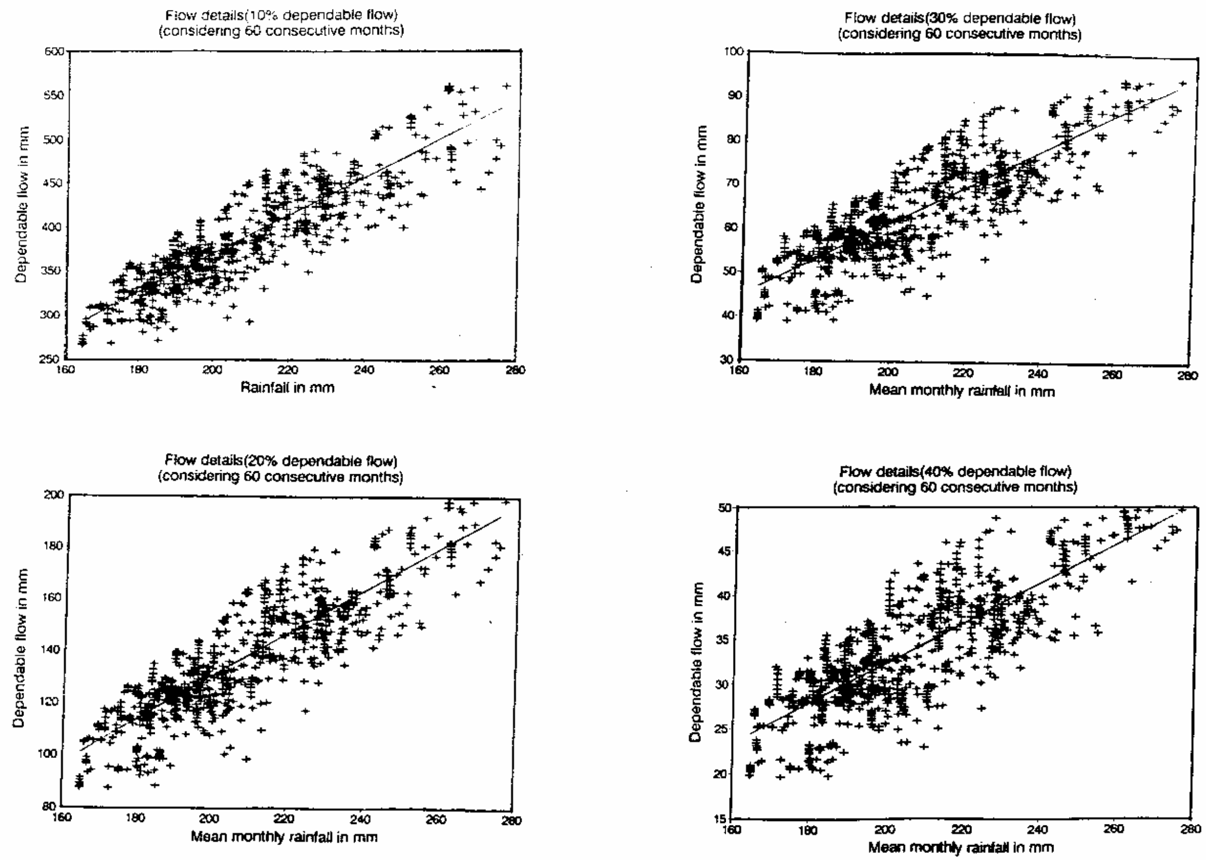
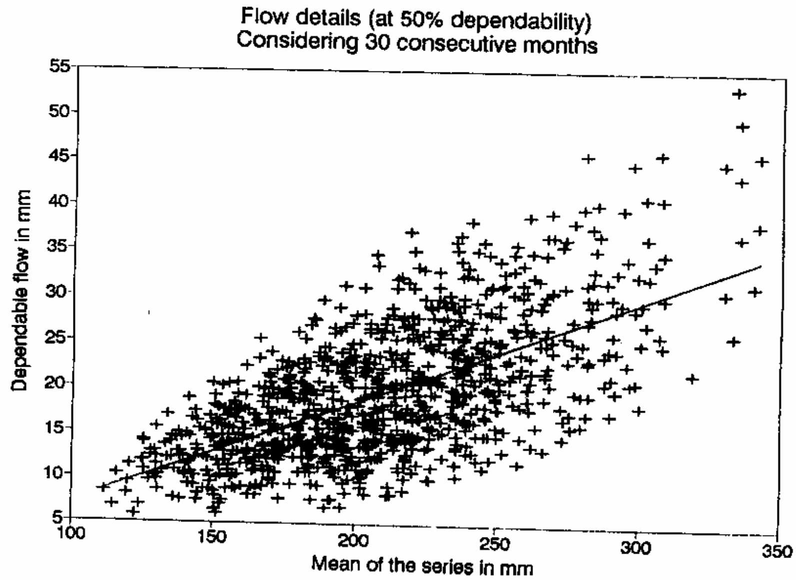


Figure 13: Plots of average rainfall and dependable flows considering 60 consecutive months and 10, 20, 30 and 40 percent depenable flows.



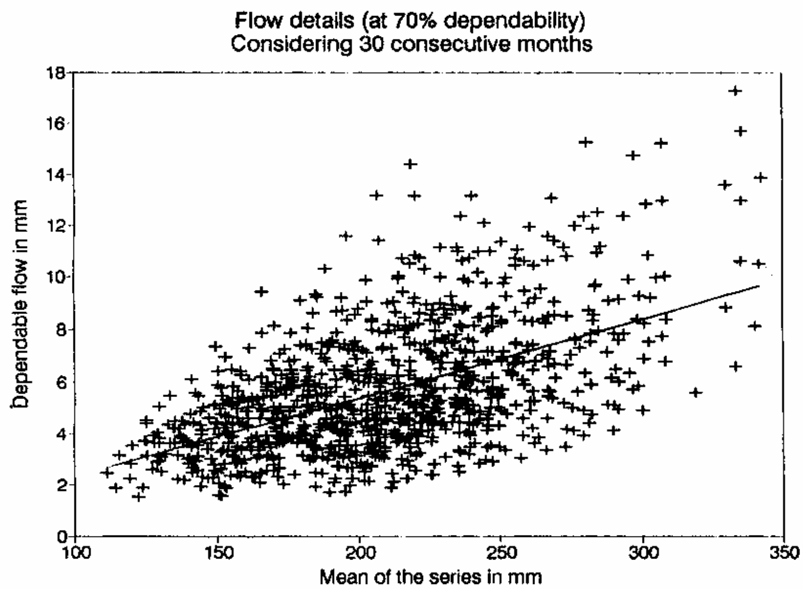
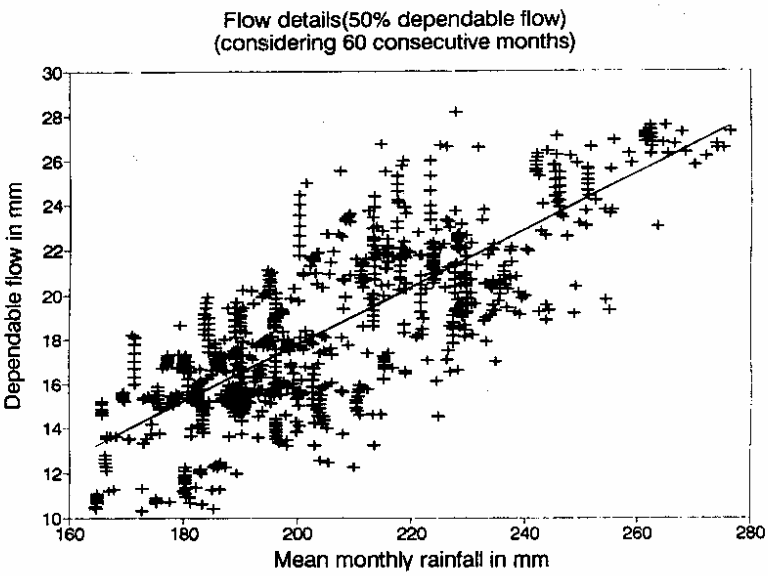


Figure 14: Plots of average rainfall and 50 and 70 percent dependable flows considering 30 consecutive months



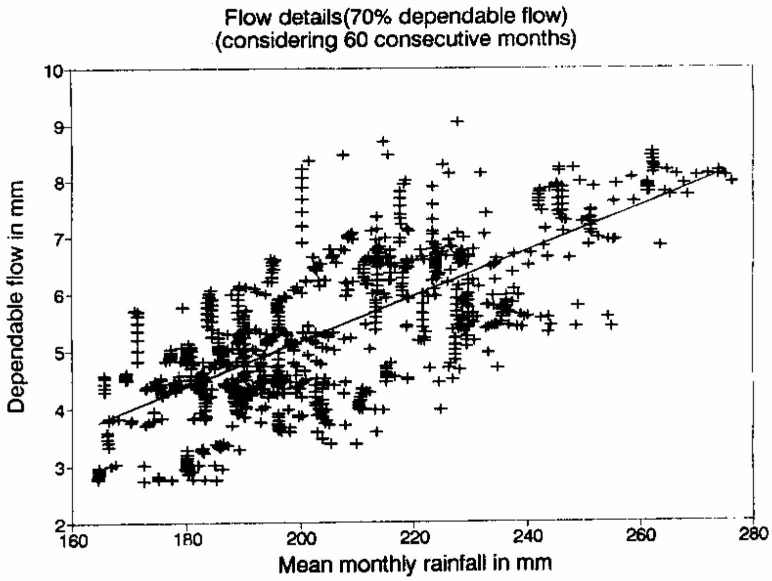
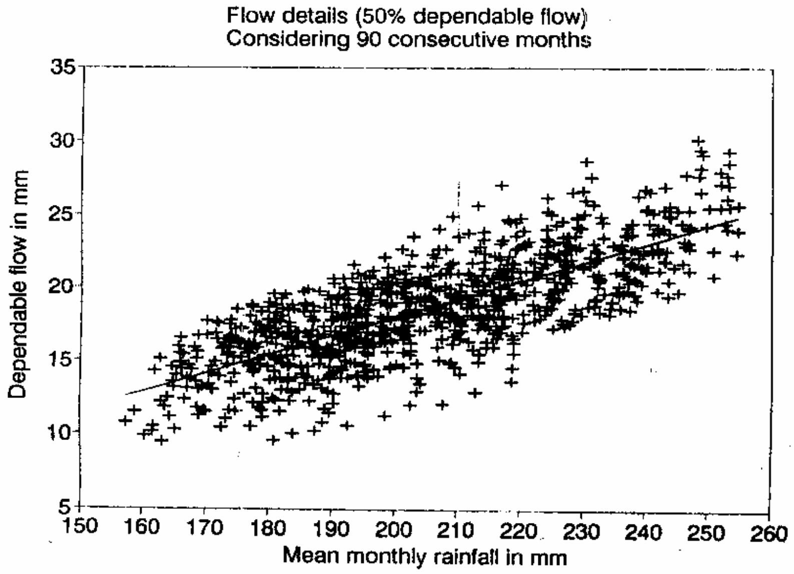


Figure 15: Plots of average rainfall and 50 and 70 percent dependable flows considering 60 consecutive months



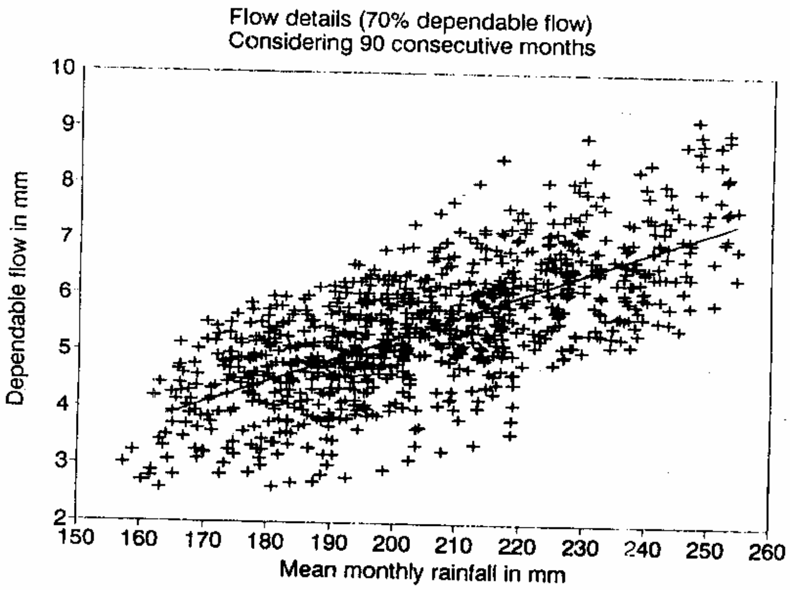
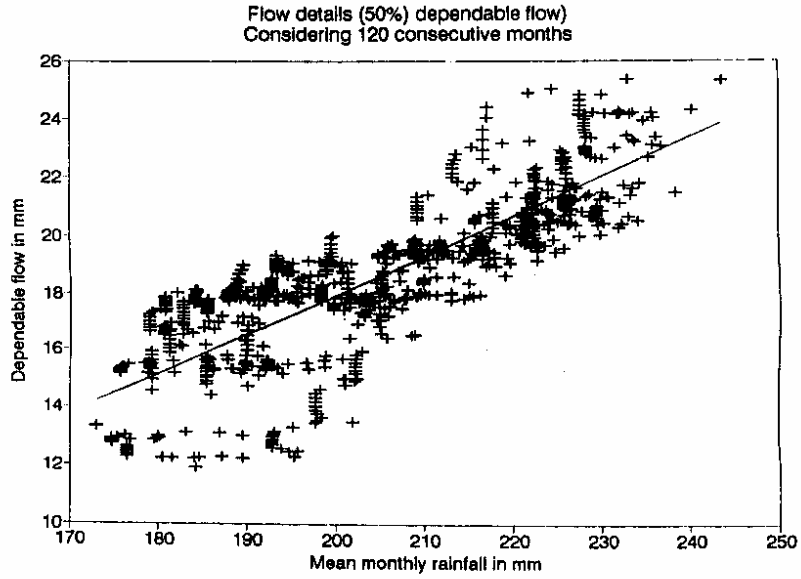


Figure 16: Plots of average rainfall and 50 and 70 percent dependable flows considering 90 consecutive months



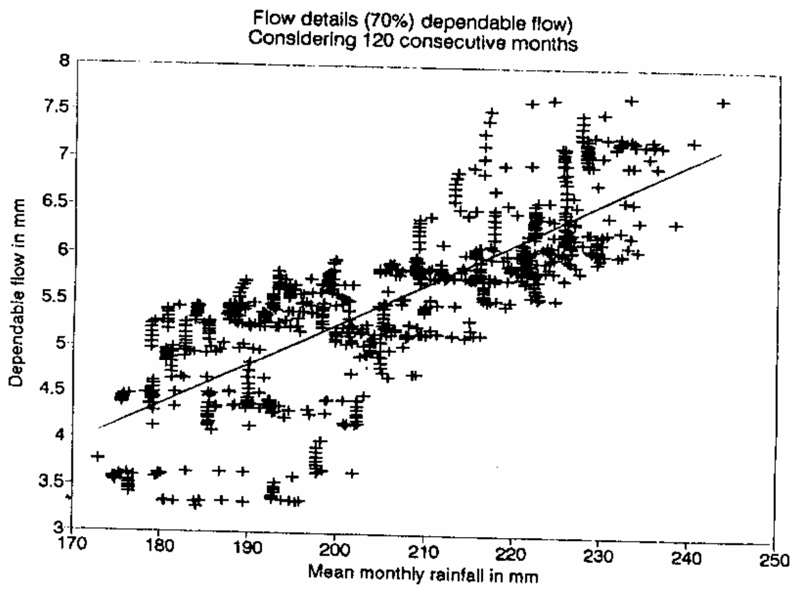


Figure 17: Plots of average rainfall and 50 and 70 percent dependable flows considering 120 consecutive months

Considering the basin average monthly rainfall and modelled runoff records of complete period, mean monthly rainfall and dependable flows for different percent of time are computed. As these values are obtained using the best available records for the basin, these are called here as true values.

Percent deviation in the values of dependable flows for different set and for different dependabilities from the true dependable flows are obtained to determine the deviation of the flow values from the true values corresponding to changes in length of sets. These values are given in Table 6.

To study the effect of wet and dry periods on the water availability, the two dry periods are merged together as there is not much difference in mean monthly and yearly rainfall and runoff values and also in average dependable flow values. Further analysis is based on wet, dry and complete periods of record.

To observe whether the best fit equation can be used further, using the best fit equations for different sets and for different percent of time, and true values of mean monthly rainfall for complete period (Table 4), dependable flow values corresponding to true values of mean monthly rainfall for complete period are computed. These flow values are compared with the flow values as obtained by using the best fit equation of a particular set and its mean rainfall value as computed earlier. These values and their comparative statement is produced here as Table 7.

Table 6: Percent deviation in dependable flow values as computed using different sets and complete length of data

Percent of time flow exceeded	Dependable flow for Complete length in mm	Total number of months considered in each set															
		30	60	90	120	150	180	210	240	30	60	90	120	150	180	210	240
		Average dependable flow values for different sets of months in mm								Percent deviation in average dependable flow values as compared to dependable flow values computed using complete record							
0	353.97	410.8	381.7	376.5	373.0	372.9	372.5	372.2	372.1	16.1	7.8	6.4	5.4	5.3	5.2	5.2	5.1
20	126.99	143.2	134.7	133.9	133.1	133.5	133.6	133.8	133.9	12.8	6.1	5.4	4.8	5.1	5.2	5.4	5.4
30	60.64	67.2	63.6	63.6	63.4	63.7	63.8	64.0	64.1	10.8	4.9	4.9	4.6	5.0	5.2	5.5	5.7
40	32.26	35.3	33.5	33.7	33.6	33.8	34.0	34.1	34.1	9.4	3.8	4.5	4.2	4.8	5.4	5.7	5.7
50	17.9	19.4	18.5	18.6	18.6	18.8	18.9	18.9	19.0	8.4	3.4	3.9	3.9	5.0	5.6	5.6	6.1
60	9.93	10.7	10.2	10.3	10.3	10.4	10.5	10.5	10.6	7.8	2.7	3.7	3.7	4.7	5.7	5.7	6.7
70	5.28	5.6	5.4	5.5	5.5	5.5	5.6	5.6	5.6	6.1	2.3	4.2	4.2	4.2	6.1	6.1	6.1
80	2.52	2.7	2.5	2.6	2.6	2.6	2.7	2.7	2.7	7.1	-0.8	3.2	3.2	3.2	7.1	7.1	7.1

Table 7: Percent departure of dependable flow values of different sets as compared to the complete record computed using the best fit equation and average rainfall values

Percent dependability	Number of consecutive months considered and flow values considering the best fit line and average rainfall considering															
	30		60		90		120		150		180		210		240	
	set value	true value	set value	true value	set value	true value	set value	true value	set value	true value	set value	true value	set value	true value	set value	true value
10	410.9	389.9	381.8	372.2	376.4	366.7	372.9	363.9	373.0	362.4	372.5	362.0	372.3	360.6	372.2	360.2
20	143.3	136.3	134.7	131.1	133.8	130.3	133.1	129.6	133.5	129.6	133.7	129.6	133.8	129.3	133.9	129.1
30	67.2	64.1	63.6	61.8	63.5	61.8	63.3	61.6	63.7	61.7	63.8	61.8	64.0	61.8	64.1	61.7
40	35.3	33.7	33.4	32.5	33.6	32.7	33.6	32.6	33.9	32.8	34.0	32.8	34.1	32.9	34.2	32.8
50	19.4	18.5	18.5	17.9	18.6	18.1	18.6	18.0	18.8	18.2	18.9	18.2	18.9	18.2	19.0	18.2
60	10.7	10.2	8.2	7.9	10.3	10.0	10.3	10.0	10.4	10.1	10.5	10.1	10.5	10.1	10.6	10.1
70	5.6	5.4	5.4	5.2	5.4	5.3	5.5	5.3	5.5	5.3	5.6	5.4	5.6	5.4	5.6	5.4
80	2.7	2.6	2.5	2.5	2.6	2.5	2.6	2.5	2.6	2.6	2.7	2.6	2.7	2.6	2.7	2.6

.... contd.

.... Table 7 contd

Percent dependa bility	Percent difference in sets considering different number of consecutive months							
	30	**60**	**90**	**120**	**150**	**180**	**210**	**240**
10	5.1	2.5	2.6	2.4	2.8	2.8	3.1	3.2
20	4.8	2.7	2.7	2.6	3.0	3.1	3.3	3.6
30	4.7	2.8	2.7	2.8	3.1	3.3	3.5	3.8
40	4.5	2.9	2.8	2.9	3.2	3.4	3.6	4.0
50	4.4	3.0	2.8	3.0	3.3	3.5	3.7	4.2
60	4.2	3.9	2.8	3.2	3.4	3.7	3.8	4.3
70	4.1	3.3	2.9	3.3	3.5	3.8	3.9	4.5
80	3.9	3.4	3.0	3.4	3.6	4.0	4.1	4.8

4. Result discussions

From the Figs. 6, 7 and 8 it is indicated that modelled flows and flow duration curves as obtained by all the models except model M3 which is a statistical model, are in good agreement with that of recorded ones. However, flow duration curves of yearly and monthly runoff values (Fig. 7 and 8), depict that M4 model which is a 5 parameter water balance model, closely produces the recorded series behaviour. Some common structures of rainfall-runoff models have been tested earlier, on some Indian catchments, including Damanganga basin (NIH, 1995-96), and it was found that for humid and semi-humid catchments water balance models are best suited. Moreover, Beven (1989) has also reported that three to five parameters in a model should be sufficient to reproduce most of the information in a hydrological record. Therefore, for further analysis, runoff series for the period 1901 to 1984 is generated using the M4 model and its calibrated parameters.

To test whether the selected M4 model performs well during the calibration period only or for the whole period from 1901-84, average annual rainfall and recorded and computed runoff values for the period 1901-84 as well as 1972-83 are compared and reproduced here.

Period	Average annual		
	Rainfall	Recorded runoff	Computed runoff
1901-84	2406 mm	-	1528 mm
1974-83	2270 mm	1345 mm	1344 mm

It gives observed and/or computed runoff value during the period as about 60 percent of rainfall value while during the period 1901-84 it is about 63 percent of rainfall value.

Based on Fig. 9, and Table 4 which indicate the dependable flow values on monthly basis, at lower dependabilities, wet period gives higher dependable flow as compared to the complete period where as for higher dependabilities viz. above 50 % all curves give similar results. As flow in river occurs only during monsoon months this result is quite obvious. However, from Table 8 which provides percent deviation in values of dependable flows of wet and dry periods from the complete period, for wet period the deviation varies from 19 to 23 percent and for dry period from 8 to 11 percent. Fig.10 is a plot of dependable flow on yearly basis and here the effect of wet and dry periods is clearly indicated. Wet period gives deviation of 7 to 33 percent while dry period the average deviation is about 10 percent (Table 8). Thus it is clear from these figures and tables that effect of dry and/or wet period plays a crucial role as far as water availability of the basin is concerned.

Table 8: Percent deviation in dependable flow values for wet and dry periods as compared to the complete period.

Period	Mean rainfall in mm	Mean runoff in mm	Dependability in percent								
			10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
On monthly basis											
Wet period	13.5	19.9	18.6	19.7	19.7	21.9	22.2	20.0	22.0	22.6	23.1
Dry period	-7.4	-11.0	-8.3	-9.1	-9.0	-9.0	-10.2	-10:6	-10.2	-10.5	-11.5
On yearly basis											
Wet period	13.5	19.9	7.2	11.4	14.5	17.2	19.8	22.4	25.2	28.8	33.8
Dry period	-7.4	-11.0	-10.0	-9.9	-9.9	-9.8	-9.8	-9.7	-9.7	-9.6	-9.5

Based on other criterion, average dependable flows at different percent dependabilities, corresponding to sets of 30 to 240 months are given in Table 6. This

Table also includes the dependable flows computed using the runoff record of complete period and the percent deviation of dependable flow values of different sets period dependable flows. It is indicated from this table that in general, as percent dependability increases, percent deviation also increases. Also if series of 90 consecutive months or more is considered then percent deviation is almost consistent. It indicates that for computation of monthly dependable flows for the Damanganga basin, a minimum of 7.5 years of data should be considered.

Table 7 indicates the dependable flow values as obtained, considering the best fit equation and the true value of average monthly rainfall. These values are compared with the average dependable flow values of a particular set and at a particular percent of time. When these values are compared with the respective values from Table 6, not much difference is observed for flow values beyond sets of 90 months. Also from this table it is indicated that all the sets beyond 30 months, deviation is more of less a constant. Thus, if for a basin located in similar region, short term rainfall-runoff record along with long term average rainfall value is available, then a relationship between mean rainfall and dependable flow values can be constructed and then using this relationship and the long term average rainfall, modified dependable flow values can be computed for further use.

5. Concluding Remarks

In the present analysis, effect of periodicity i.e. wet and dry spells on the water availability of a basin, is examined. The analysis is performed in two steps. In the first step, effect of wet and dry spells on the water availability is examined. It is observed that on yearly basis, its effect is more pronounced as compared to monthly basis. Also for wet spells, an increase of about 23 percent and 34 percent respectively, on monthly and yearly basis is observed. For dry spells, this decrease is about 11 percent for monthly and yearly water availability computations.

In the second step, effect of length of data on the water availability is examined. As different sets of consecutive months are considered, dry as well wet spells in the data are automatically got included and the best fit line obtained thus contains the effect of these periods. Based on this analysis, it is observed that for water availability analysis on monthly basis for Damnanganga basin, a minimum of 90 months of record length is needed and for computation of water availability at higher dependabilities, flow record must be of sufficient length so as to represent the both dry and wet periods effectively to avoid the over and/or under estimation of flow values.

For shorter length of records, a relationship between percent dependable flow value and mean rainfall can be established and then using this relationship and long term average rainfall value, dependable flow values can be modified to represent the long term trend and behaviour of rainfall.

The above analysis is solely based on the data of a single basin and before generalising these conclusions, similar type of analysis need to be conducted on more basins located in same as well as other agro-climatic zones of the country.

References

Beven, K., 'Changing ideas in hydrology : the case of physically-based models', *J. Hydrol.*,105, 1989, p. 157-172.

Hughes, D. A. & Smakhtin V., 'Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves', Hydrological Sciences Journal, vol. 41(6), December,1996 ,p.851-871.

Hughes, D. A., 'Monthly rainfall-runoff models applied to arid and semiarid catchments for water resource estimation purposes', *Hydrol. Sci. J.*, Vol. **40**, 1995, p. 751-769.

Khosla, A. N., 'Analysis and utilization of data for the appraisal of water resources', J. Irrig. Power, India, Oct., 1949, p. 410-422.

Mimikou, M. & Rao, R. 'A regional monthly rainfall-runoff model', J. Wat. Resour. Plan. Manag., ASCE 109(1), 1983, p. 75-93

Murry, J. N. and Prsad, K. N., 'Relation between basin characteristics and discharges (peak and annual)' In: A study of Indian catchments, (7th Symp. Water Resources, Banglore, India) A17, 1971, p. 1-30.

NIH Report No. CS(AR) 211, 'Comparison of monthly rainfall-runoff models', National Institute of Hydrology, Roorkee, 1995-96.

Percent dependability	Flow in mm	Period			Percent difference		
		Whole	Wet	Dry	Whole	Wet	Dry
(a) Considering 30 consecutive months							
10	410.9	389.9	464.3	348.6	5.1	-13.0	15.1
20	143.3	136.3	161.0	122.6	4.8	-12.4	14.4
30	67.2	64.1	75.2	57.9	4.7	-11.9	13.9
40	35.3	33.7	39.4	30.6	4.5	-11.5	13.4
50	19.4	18.5	21.6	16.9	4.4	-11.2	13.0
60	10.7	10.2	11.8	9.3	4.2	-10.8	12.6
70	5.6	5.4	6.2	4.9	4.1	-10.4	12.2
80	2.7	2.6	2.9	2.4	3.9	-10.0	11.7
(b) Considering 90 consecutive months							
10	376.4	366.7	430.4	331.4	2.6	-14.3	12.0
20	133.8	130.3	153.7	117.3	2.7	-14.8	12.4
30	63.5	61.8	73.2	55.5	2.7	-15.1	12.6
40	33.6	32.7	38.8	29.3	2.8	-15.4	12.9
50	18.6	18.1	21.5	16.2	2.8	-15.7	13.1
60	10.3	10.0	11.9	8.9	2.8	-15.9	13.3
70	5.4	5.3	6.3	4.7	2.9	-16.2	13.5
80	2.6	2.5	3.0	2.2	3.0	-16.5	13.7

Table contd ....

.... Contd

Percent dependability	Flow in mm	Period			Percent difference		
		Whole	Wet	Dry	Whole	Wet	Dry
(c) Considering 180 consecutive months							
0	370.8	362.0	420.1	329.7	2.4	-13.3	11.1
20	133.0	129.6	152.2	116.9	2.6	-14.5	12.1
30	63.5	61.8	73.2	55.4	2.7	-15.3	12.8
40	33.8	32.8	39.2	29.3	2.9	-16.0	13.3
50	18.8	18.2	21.9	16.1	3.0	-16.7	13.9
60	10.4	10.1	12.2	8.9	3.1	-17.3	14.4
70	5.5	5.4	6.5	4.7	3.2	-18.0	15.0
80	2.6	2.6	3.1	2.2	3.4	-18.8	15.6
(d) Considering 240 consecutive months							
10	369.0	360.2	418.1	328.0	2.4	-13.3	11.1
20	132.6	129.1	152.1	116.4	2.6	-14.7	12.2
30	63.4	61.7	73.3	55.2	2.8	-15.6	13.0
40	33.8	32.8	39.4	29.2	2.9	-16.5	13.7
50	18.8	18.2	22.0	16.1	3.1	-17.2	14.4
60	10.4	10.1	12.3	8.9	3.2	-18.0	15.0
70	5.6	5.4	6.6	4.7	3.4	-18.8	15.6
80	2.7	2.6	3.2	2.2	3.5	-19.9	16.4

DIRECTOR : S M SETH

STUDY GROUP

R D SINGH, DIVISIONAL HEAD
R MEHROTRA, SCIENTIST