RAINFALL-RUNOFF MODELLING IN THE BHARATHAPUZHA RIVER BASIN

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PROJECT REPORT

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Malappuram
1999

CERTIFICATE

Certified that this project report, entitled **"RAINFALL-RUNOFF MODELLING IN THE BHARATHAPUZHA RIVER BASIN"** is a record of project work done jointly by Aji,R.,Jayakrishnan,B.V.and Najash Babu,K. under my guidance and supervision and it has not previously formed the basis for the award of any degree,diploma,fellowship or associateship to them.

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Date : 17/12/99

DECLARATION

We hereby declare that this project report entitled **"RAINFALL-RUNOFF MODELLING IN THE BHARATHAPUZHA RIVER BASIN"** is a bonafide record of project work done by us during the course of project and that report has not previously formed on the basis for the award to us of any degree,diploma,fellowship or other similar title of any other University or Society.

Aji,R.

Jayakrishnan,B.V

Najash Babu,K.

Place:Tavanur

Date: 17th DEC 1999

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

cm	Centimetre
E	East
km	Kilometre
km^2	Kilometre squared
mm	Millimetre
M.S.L.	Mean Sea Level
N	North
P	Precipitation
R	Runoff
r	Correlation co-efficient
R^2	Co-efficient of determination
RF	Rainfall
Se	Standard error
Sy, S.D.	Standard Deviation
^{0}	Degrees
'	Minutes
%	Percentage

INTRODUCTION

Kerala, lying between 8^{0} 18' and 12^{0} 22'N latitude and 74^{0} 52' and 77^{0} 22'E longitude is a relatively small state,consisting of only about 1.3 per cent of the total land area of India.

Kerala has forty four rivers with lengths more than 15 km originating from the Western Ghats, out of which forty one flow towards the west and join the Arabian Sea. The remaining three rivers flow towards the east and after joining the Cauvery system drain into the Bay of Bengal. The average annual rainfall of the state is estimated as 3080 mm. The non-uniformity in the spatial and temporal distribution of rainfall is mainly responsible for the frequent occurence of droughts and floods in Kerala. The average annual rainfall in the low lands of Kerala ranges from 900 mm in the south to 3500 mm in the north. In the highlands, annual rainfall ranges from 2500 mm in the south to 6000 mm in the north. About 60 per cent of the annual rainfall in the state is received during the South-West Monsoon (June to August), 25 per cent during the North-East Monsoon (September to November) and the remaining during the summer period.

Rivers have been the pivotal points around which the world's civilizations have originated. Bharatapuzha is the second longest river in Kerala after Periyar and originates from the Anamalai hills in the Coimbatore district of Tamil Nadu and joins the Arabian Sea at Ponnani in the Malappuram district of Kerala. During its journey, it passes through 11 taluks and 4000 villages out of which, about 175 villages are totally dependent on it for the drinking water supply.

The calculation of runoff volume (yield) is of great importance in all water resources development studies. The various methods used for the estimation of yield are

Correlation of stream flow and rainfall, Empirical equations, and Watershed simulation.

The relationship between rainfall and resulting runoff is quite complex and is influenced by a host of factors related to the catchment and climate. Further, there is the problem of paucity of data which forces one to adopt suitable methods for the adequate estimation of runoff. One of the most common methods used for estimating the yield is the correlation of runoff with rainfall and it is very much suited for places without adequate data.

The specific objectives of this study are

1. Analysis of rainfall and runoff data of Bharatapuzha basin.
2. Development of regression equations connecting rainfall with runoff for the different gauging stations.
3. Evaluation of the models developed.

REVIEW OF LITERATURE

Drissel and Osborn (1968) analysed the variability in rainfall affecting runoff for the Alamogordo Creek watershed in New Mexico. The variation in runoff yields for the period of record was analysed and the distribution and orographic effects were discovered. They also compared the ten years mean annual, seasonal and monthly variations with the long term averages of nearby weather stations.

Bonne (1971) developed a model for the simulation of monthly stream flow series by multiple regression approach which include both precipitation and stream flow. The variables in regression function represented the previous month's flow, current precipitation, antecedent month's precipitation and the current stream flow as the dependent variable. Stream flows were simulated for three different watersheds with different physiographic characteristics and the results were compared with the historic record in terms of statistical parameters and frequency distibution and also with a simple regression model. He concluded that in most of the cases a definite improvement is achieved by the multiple regression model over the simple regression model.

Sarma, Delleur and Rao (1973) analysed the relative regeneration performance of five linear rainfall excess - direct runoff models for several urban watersheds with varying degree of development and concluded that the quality of regeneration for larger basin is less than that found for smaller basins.

Singh and Birsoy (1977) developed relationships between statistical parameters of annual rainfall and those of annual runoff. The transformation of rainfall into runoff is characterised by a single linear reservoir model. They concluded that for large carry over, the distribution of runoff always tends to be normal regardless of the distribution of rainfall.

Kitanidis and Bras (1979) found that the correlation existing between the explanatory variables of statistical rainfall runoff models of the regression type has significant effects on the values of rainfall - runoff model parameters and the ridge regression technique could be used to obtain well behaved model coefficients. They showed that considerable amount of data is required to achieve parameter stability, casting serious doubts on the predictive capabilities of models developed using limited historical data.

James and Mohanan (1981) evolved a simple deterministic black-box model for the simulation of monthly rainfall - runoff process in the monsoon season for the Chaliyar basin on the Malabar coast. The monthly rainfall - runoff regression model showed non-linear characteristics. The accuracy of the calibration model was also verified using the data for the calibration period from the sub-basin.

Kothyari and Garde (1991) analysed rainfall- runoff data from 55 non-snow fed catchments in the Indian sub-continent to study the influence of selected climatic, topographic and land-use variables on the mean annual runoff and obtained a regression model of the form

$$R_m = C\,(P_m - 1.4\,T_m)^{0.9}\, f_v^{\,0.2}\, A^{0.04}\, T_m^{-0.95}$$

where R_m is the mean annual runoff (cm)

P_m is the mean annual rainfall (cm)

T_m is the mean annual temperature (^{0}C)

f_v is the vegetal cover factor.

A is the catchment area (km^2)

They found that the co-efficient of variation of annual runoff (CR) is related with the co-efficient of variation of annual rainfall (CP) as

$$CR = 2.23\ CP - 0.05.$$

Jayasree (1992) conducted regression and correlation studies on Chaliyar basin to find the relationship between rainfall and runoff of the sub-basin and prediction equations have also been found out.

Mimikov and Baltas (1996) conducted a study in Central Greece and a rainfall-runoff model for flood-flow forecasting using mean annual rainfall and annual areal radar rainfall information was obtained by using the unit hydrograph approach . They observed that the model gave better results when radar processed weather data are given as input.

Kothyari and Singh (1999)developed a multiple-input single-output time-invariant non-linear model based on a black-box system approach using daily data and it was used for flow forecasting during monsoon flood events.

MATERIALS AND METHODS

3.1. Description of the Study Area.

Bharatapuzha is the second longest river in the south-west coast of India. It originates from the Anamalai Hills in the Western Ghats at an elevation of 1964 m above M.S.L. and flows through Coimbatore district of Tamil Nadu and Palakkad, Thrissur and Malappuram districts of Kerala, to join the Arabian sea at Ponnani. Bharatapuzha has a total length of 209 km and a total basin area of 6186 km^2 of which 4400 km^2 is in the Kerala state and the remaining is in Tamil Nadu. The drainage map of Bharatapuzha basin is shown in figure 1. About 80 percent of the area of Palakkad (approximately about 600 km^2) is situated in Bharatapuzha basin.

Bharatapuzha has twenty tributaries, out of which there are four major tributaries. The main tributaries of Bharatapuzha are

1. Gayathri Puzha,
2. Chittur Puzha, (Kannadi or Amaravathi),
3. Kalpathi Puzha, and
4. Thutha Puzha.

3.1.1. Climate.

The Bharatapuzha basin experiences two distinct monsoons, namely the South-West Monsoon (June-August) and the North-East Monsoon (September-November). These two monsoons accounts for about 85 per cent of the annual rainfall. The average annual rainfall in the state is about 308 cm where as the same for the basin is estimated to be 250 cm.

3.1.2. Hydrological Stations

Bharatapuzha basin is covered by a network of thirty nine raingauge stations (Table 1), seven river gauge stations (Table 2) and two evaporation stations (Table 3).

Table 1. Rain Gauge Stations in Bharatapuzha River Basin.

Sl. No.	Name of the Station
1.	Alathur.
2.	Cheerakuzhy.
3.	Chittur.
4.	Chulliar.
5.	Cherplachery.
6.	Erumayoor.
7.	Erutempathy LSF.
8.	Kunnamkattupathy.
9.	Koduvayoor.
10.	Malampuzha Dam.
11.	Manalaroor Estate.
12.	Mangalam Dam.
13.	Mannarghat.
14.	Meenakkara Dam.
15.	Meera Flores Estate.
16.	Moolathara Anicot.
17.	Mathur.

18.	Manakadavu.
19.	Maluserikavu.
20.	Nelliampathy.
21	Nurnee.
22.	Olavakotu.
23.	Ottappalam.
24.	Palghat.
25.	Pokkunni.
26.	Ponnani.
27.	Pattambi.
28.	Pothundi.
29.	Parur.
30.	Pazhavannur seed farm.
31.	Pulickal.
32.	Silent Valley.
33.	Sungam.
34.	Shornur Railway Station.
35.	Thrithala.
36.	Thembaramadakku.
37.	Vadakkenchery.
38.	Walayar.
39.	Elanadu.

Table 2. River Gauge Stations in Bharatapuzha River Basin.

Sl No.	Name of the Station
1.	Thiruvegapura.
2.	Kuttippuram
3.	Thrithala
4.	Pampady
5.	Cheruthuruthy
6.	Cheerakuzhy
7.	Manakkadavu

Table 3. Evaporation Stations in Baharatapuzha River Basin.

Sl No.	Name of Station
1.	Malampuzha
2.	Pattambi.

3.2. Data Collection .

The monthly runoff and rainfall datas for ten years duration (1982-1991) from the river gauge stations and rain gauge stations in the Bharatapuzha river basin were procured from the Field Studies Circle (Irrigation Department) at Thrissur.

The drainage area contributing to a river gauge station is considered as a sub-basin. In the Manakadavu sub-basin, the only rain gauge station available is at Manakadavu and is not representative to the sub-basin. Therefore that sub-basin is not considered in the present study.

3.3. Computation of the Average Rainfall for the Sub-basins.

Each sub-basin consists of a network of rain gauge stations. For the analysis, the average rainfall for each sub-basin was computed.

3.4. Correlating Runoff with Rainfall.

The monthly runoff and rainfall values were correlated for each sub-basin.

The co-efficient of correlation 'r' can be calculated as,

$$r = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{\sqrt{[N(\Sigma P^2) - (\Sigma P)^2] \cdot [N(\Sigma R^2) - (\Sigma R)^2]}}$$

A value of r between 0.6 and 1.0 indicates good correlation.

3.4.1. Correlating Monthly Discharge with Monthly Rainfall.

Monthly runoff and rainfall for each year for the 10 year period were correlated and the correlation co-efficients were found.

3.4.2. Correlating Discharge with Rainfall of a Month for the 10 year period.

Monthly discharge and rainfall values of a year for the 10 year period was correlated. For each sub-basin, the correlation coefficients for all the months were found.

3.5. Development of Models.

3.5.1. Estimation of Runoff by the Simple Linear Regression Methods.

The equation for straight line regression between runoff 'R' and rainfall 'P' is

$$R = aP+b.$$

and the values of the co-efficients 'a' and 'b' are given by

$$a = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{N(\Sigma P^2) - (\Sigma P)^2}, \text{ and}$$

$$b = \frac{\Sigma R - a\,\Sigma P}{N}$$

in which N is the number of observation sets R and P

3.5.1. Estimation of Statistical Parameters.

The ten year average monthly run off values were plotted against the ten year average rainfall and the line of best fit was drawn. The straight line regression equation is obtained. The co-efficient of determination (R^2), standard error of the estimate, standard deviation and co-efficient of correlation (r) were found out. If the standard error of the estimate is near to standard deviation , the regression model is not successful and as it nears to the zero value , the reliability of model increases. The percentage of ratio of standard error to standard deviation was also found out

The co-efficient of determination, R^2, is obtained by,

$$R^2 = \frac{\text{Sum of squares due to regression}}{\text{Sum of squares corrected for mean}}$$

$$= \frac{\Sigma(\hat{y}_i - \bar{y})^2}{\Sigma(y_i - \bar{y})^2}$$

Where $\hat{y}_i$ is the predicted runoff values

$\bar{y}$ is the mean of predicted runoff

y_i is the observed runoff value

The standard error of estimate is obtained by,

$$Se = \left[\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n - p} \right]$$

Where n is the sample size

p is the number of unknowns

y_i is the predicted runoff values

The standard deviation is obtained by,

$$Sy = \left[\frac{1}{n-1} \left[\sum_{i=1}^{n} y_i^2 - \frac{1}{n} \left[\sum_{i=1}^{n} yi \right]^2 \right] \right]^{0.5}$$

For the Kuttippuram river gauge station, the monthly average values of all the twelve months were taken for developing the equation. For the other stations, the rainfall in monsoon months were only considered due to unavailability of sufficient data.

3.5.2. Estimation of Runoff using the rainfall of the same month and Preceding 'n' months.

The equation developed are of the form

$$R_m = a + b_1 P_m + b_2 P_{m-1} + \ldots\ldots\ldots\ldots\ldots + b_n P_{m-n+1}$$

where R_m is the monthly rainfall of month 'm'

P_{m-1} is monthly rainfall of month preceding the month 'm'

P_{m-n+1} is the monthly rainfall of the $(n-1)^{th}$ month preceding the month 'm'

$a_1, b_1, b_2, \ldots\ldots\ldots\ldots\ldots b_n$ are estimated parameters.

For the Kuttippuram sub-basin, models were developed for all the 12 months and for all the other sub-basins only the monsoon months are considered. R^2 values, standard deviation, standard error, and the percentage of ratio of standard error to standard deviation (Se/SD %) were also found out.

The analysis work was done using the software packges Microsoft Excel and Microcal Origin.

RESULTS AND DISCUSSION

The rainfall and runoff data of Bharatapuzha basin were analysed with a view to identify the relationship between the rainfall-runoff processes and to find the correlation between these processes. The results inferred from the analysis of these data are presented and discussed below.

4.1. Average Rainfall Values.

The average rainfall values for the six sub-basins of Bharatapuzha were calculated using Arithmetic Mean Method and is presented in Appendix 1. The distribution of mean monthly rainfall for all the rivergauge stations is shown in Figure 2.

4.2. Rainfall - Runoff Correlation.

The co-efficient of correlation between the rainfall and runoff values for each sub-basin of the Bharatapuzha river basin were estimated. The co-efficient of correlation between the monthly rainfall and runoff for 10 years were determined and presented in Table 4.

The highest co-efficient of correlation obtained was 0.97505 for Cheerakuzhy where only nine years data was considered where as the lowest value obtained was 0.717 for the Thiruvegapura sub-basin.

The co-efficient of correlation of rainfall and runoff values for different months were determined and presented in Table 5. The correlation represented poor

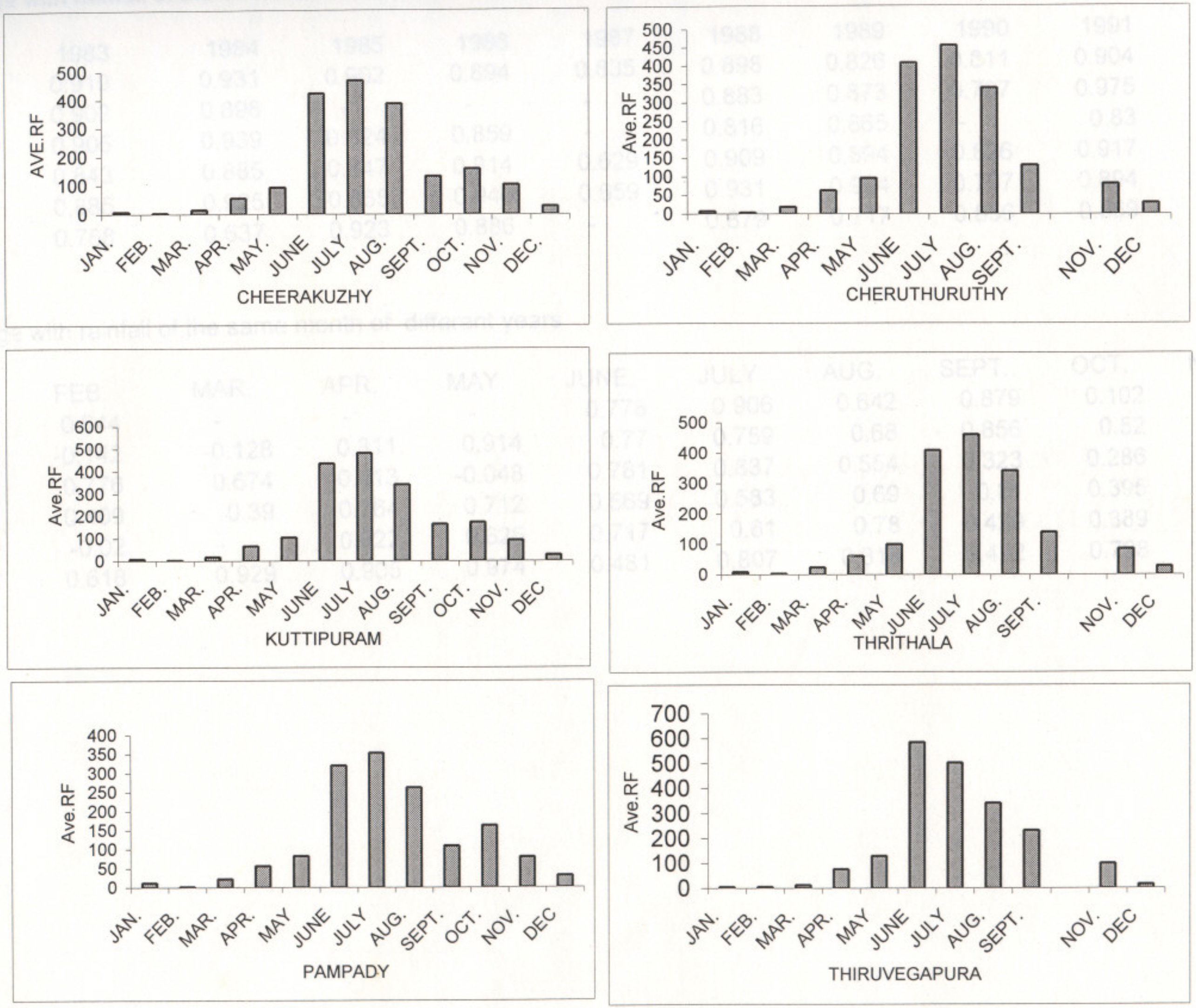
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Fig.2

Table 4.

Correlating monthly discharge with rainfall of the same month of a year.

YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Kuttipuram	0.898	0.919	0.931	0.902	0.894	0.835	0.898	0.826	0.811	0.904
Cheerakuzhy.	0.952	0.902	0.898	-	-	-	0.883	0.873	0.797	0.975
Pampady.	0.815	0.906	0.939	0.924	0.859	-	0.816	0.865	-	0.83
Cheruthuruthy	0.9	0.843	0.885	0.847	0.914	0.629	0.909	0.894	0.826	0.917
Thrithala	0.815	0.885	0.925	0.865	0.944	0.659	0.931	0.904	0.797	0.894
Thiruvegapura.	0.761	0.768	0.637	0.923	0.886	-	0.879	0.717	0.856	0.869

Table 5.

correlating monthly discharge with rainfall of the same month of different years

MONTH	JAN.	FEB.	MAR.	APR.	MAY.	JUNE.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Cheerakuzhy.	0.778	0.644	-	-	-	0.778	0.906	0.642	0.879	0.102	0.049	0.975
Kuttipuram.	0.429	-0.142	-0.128	0.811	0.914	0.77	0.759	0.68	0.856	0.52	0.715	0.624
pampady.	-0.326	0.776	0.674	0.413	-0.048	0.781	0.837	0.554	0.323	0.286	0.567	0.744
Cheruthuruthy.	0.392	0.409	0.39	0.764	0.712	0.569	0.583	0.69	0.81	0.395	0.681	0.935
Thrithala.	0.862	-0.02	-	0.922	0.626	0.717	0.61	0.78	0.429	0.389	0.626	0.698
Thiruvegapura.	0.47	0.618	0.929	0.905	0.974	0.481	0.807	0.318	0.422	0.708	0.658	-0.09

values during certain lean months in Pampady, Kuttippuram, and Thrithala sub-basins. However agreeable correlation were obtained in majority of the months in all sub-basins.

4.3. Development of Models.

4.3.1. Models Relating Average Rainfall and Runoff.

Mathematical models were developed using average monthly rainfall and runoff for the monsoon season for all sub-basins except Kuttippuram. For Kuttippuram sub-basin, the rainfall and runoff values for all the months were taken. Average monthly rainfall and runoff values are given in Tables 6 to 11. Graphs plotted with rainfall against runoff are given in Figures 3 to 8. The rainfall runoff relationship in each sub-basin could be expressed by a relationship of the form y = ax + b with high correlation co-efficients. The R^2 values obtained has a maximum value of 0.9532 for Thrithala sub-basin and a minimum value of 0.8144 for Cheruthuruthy sub-basin. The minimum Se/SD percentage value of 24.32 was obtained for Thrithala Station. The mathematical models, R^2 values, standard error, standard deviation and percentage of ratio of standard error to standard deviation for all the sub-basins are presented in Table 12.

Mathematical models were also developed using rainfall and runoff of a month for the different sub-basins. The coefficient of determination obtained has a maximum value of 0.9583 for Cheerakuzhy and a minimum value of 0.0163 for Kuttippuram. The models developed and R^2 values obtained are presented in Table 13.

4.3.2. Models Relating the Runoff of a Month with the Rainfall of the Same and Months Preceding it for Kuttippuram River Gaguge Station.

Table 6. Kuttippuram River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
9.387	74.008	40.131
3.962	29.431	32.433
18.150	12.878	52.566
66.527	9.264	121.213
105.490	38.963	176.501
435.861	420.863	645.298
481.985	764.905	710.748
342.610	708.169	512.975
165.899	344.905	262.222
173.710	299.276	273.305
93.385	243.901	159.324
27.440	105.951	65.748

Table 7. Cheruthuruthy River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
8.054	30.473	34.763
3.681	10.556	32.120
408.674	171.910	276.978
456.273	331.834	305.757
340.868	321.411	235.983
132.770	140.869	110.167
172.670	119.063	134.290
82.038	88.176	79.494
30.392	43.468	48.269

Table 8. Pampady River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
12.292	16.772	12.292
2.663	5.263	14.347
352.782	127.534	131.672
262.414	114.374	101.39
109.285	42.647	50.076
163.418	54.971	68.216
80.359	47.578	40.383
33.913	39.378	24.819

Table 9. Thrithala River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
9.695	34.113	27.374
461.131	458.511	470.666
342.334	392.535	354.013
141.045	182.175	156.355
179.881	123.063	194.490
85.591	122.609	101.901
28.909	37.952	46.242

Table 10. Thiruvegapura River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
6.342	7.725	24.755
502.415	265.733	299.331
341.985	253.509	210.533
232.731	167.814	150.061
229.084	135.608	148.042
99.626	88.015	76.387
15.484	20.540	29.814

Table 11. Cheerakuzhy River Gauge Station

Average monthly rainfall (mm)	Average monthly runoff (mm^3)	Predicted runoff (mm^3)
442.396	235.83	272.128
490.312	370.439	303.379
381.001	239.827	232.087
131.826	57.771	69.575
167.466	53.828	92.819
84.011	31.960	38.391
26.749	16.803	1.044

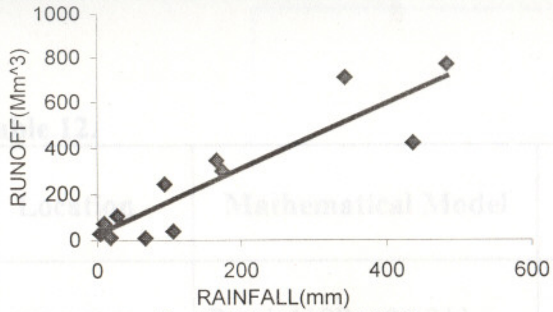

Fig.3.RAINFALL-RUNOFF RELATIONSHIP(Kuttipuram)

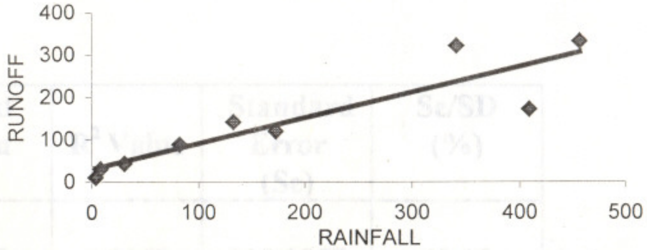

Fig.4.RAINFALL-RUNOFF RELATIONSHIP(Cheruthuruthy)

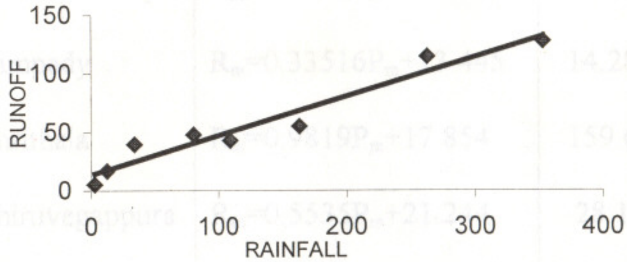

Fig.5.RAINFALL RUNOFF RELATIONSHIP(Pampady)

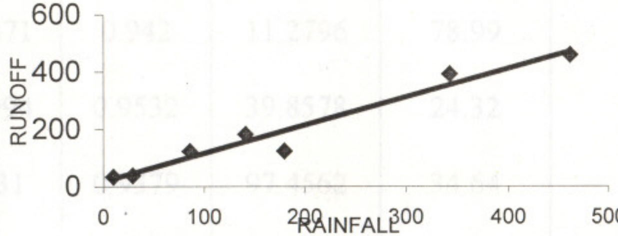

Fig.6.RAINFALL-RUNOFF RELATIONSHIP(Thrithala)

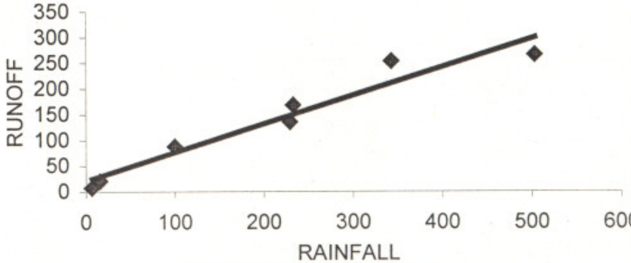

Fig.7.RAINFALL-RUNOFF RELATIONSHIP(Thiruvegapura)

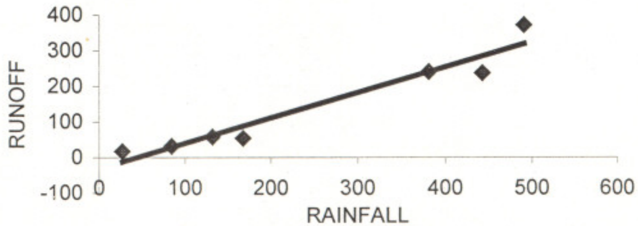

Fig.8.RAINFALL-RUNOFF RELATIONSHIP(Cheerakuzhy)

Table 12.

Location	Mathematical Model	Standard deviation (SD)	R^2 Value	Standard Error (Se)	Se/SD (%)
Kuttippuram	$R_m=1.419P_m+26.811$	247.3565	0.8168	119.1077	48.15
Cheruthuruthy	$R_m=0.6046P_m+29.894$	109.298567	0.8144	54.2755	49.84
Pampady	$R_m=0.33516P_m+13.445$	14.2816871	0.942	11.2796	78.99
Thrithala	$R_m=0.9819P_m+17.854$	159.613994	0.9532	39.8578	24.32
Thiruvegappura	$R_m=0.5535P_m+21.244$	28.131031	0.9379	97.4562	34.64
Cheerakuzhy	$R_m=0.6522P_m-16.402$	128.079	0.9507	32.8228	25.6

Table 13.

Location	Month	Mathematical Model	R^2 Value
Kuttippuram	January	R_m=0.9109P_m+65.457	0.1847
	February	R_m=-0.486 P_m+31.34068	0.02035
	March	R_m=-0.876P_m+14.467	0.0163
	April	R_m= 0.1489P_m-0.6443	0.6586
	May	R_m= 0.5374P_m-17.732	0.8353
	June	R_m= 1.038P_m-31.559	0.5929
	July	R_m= 1.0303P_m+268.3	0.5761
	August	R_m= +3.6129P_m-529.64	0.4622
	September	R_m= 1.8104P_m+44.57	0.7324
	October	R_m= 1.4676P_m+44.345	0.2706
	November	R_m= 2.1005P_m+47.743	0.511
	December	R_m=1.0683P_m+75.752	0.4221
Thrithala	June	R_m=0.6674P_m-64.95	0.5135
	July	R_m=0.8484P_m+67.282	0.3717
	August	R_m=3.0918P_m-65.88	0.6072
	September	R_m=0.6571P_m+89.493	0.1541
	October	R_m=0.492P_m+34.489	0.1514
	November	R_m=1.2767P_m+13.335	0.3918
	December	R_m=0.525P_m+22.769	0.487

(Table 13 Contd...)

Pampady	June	$R_m=0.2202P_m-3.6793$	0.6101
	July	$R_m=0.3628P_m-0.4401$	0.701
	August	$R_m=0.558P_m-32.048$	0.3073
	September	$R_m=0.1362P_m+27.763$	0.1046
	October	$R_m=0.1504P_m+30.396$	0.0822
	November	$R_m=0.646P_m-4.3327$	0.3208
	December	$R_m=-0.2907P_m+49.508m$	0.4631
Cheruthuruthy	June	$R_m=0.3878P_m+17.03m$	0.3278
	July	$R_m=0.8848P_m-34.787$	0.2862
	August	$R_m=2.7369P_m-34.787$	0.4827
	September	$R_m=1.1328P_m-19306$	0.6515
	October	$R_m=0.5284P_m+28.607$	0.1612
	November	$R_m=1.0904P_m-1.5131$	0.4909
	December	$R_m=0.8719P_m+14.23$	0.8699
Thiruvegapura	June	$R_m=0.1709P_m+49.867$	.2318
	July	$R_m=0.5708P_m-21021$	0.6525
	August	$R_m=0.301P_m+150.58$	0.1014
	September	$R_m=0.3376P_m+89.244$	0.1782
	October	$R_m=0.63.94P_m-10.859$	0.5011
	November	$R_m=0.4121P_m+46.962$	0.4327
	December	$R_m=-0.0645P_m+21.539$	0.0096
Cheerakuzhy	June	$R_m=0.6272P_m-42.641$	0.1306
	July	$R_m=1.6688P_m-466.42$	0.8267
	August	$R_m=0.8812P_m-98.766$	0.3712
	September	$R_m=0.5162P_m+6.7066$	0.9484
	October	$R_m=0.1668P_m+39.763$	0.0308
	November	$R_m=0.6762P_m-4.3038$	0.8127
	December	$R_m=0.2105P_m+12.089$	0.9583

Mathematical models were developed using runoff of a month and rainfall of same and all possible months preceding it. The mathematical models developed contained a maximum of eight parameters and a minimum of two parameters. The first model developed is of linear regression type ($y = ax + b$) and the remaining are of multiple regression type ($y = a + b_1 x_1 + b_2 x_2 + ...$).

The R^2 value obtained for the models developed using rainfall and runoff of the same month alone has a maximum value of 0.8353 for May and a minimum value of 0.0163 for March. The minimum Se/SD percentage value for the same was obtained as 3.98 for March.

When the runoff of a month is correlated with the rainfall of the same and preceding months, the maximum R^2 value obtained is 0.8473 for May and minimum value obtained is 0.0168 for March. The minimum Se/SD percentage value for the same was obtained as 12.1 for March.

When the runoff of a month and rainfall of same and preceding two months are considered for developing the model, the R^2 value obtained is maximum at 0.8914 for May and the minimum value obtained is 0.10274 for March. The minimum Se/SD percentage value for the same was obtained as 27.1 for March.

When the runoff of a month and rainfall of same and preceding three months are considered for model development the maximum value of R^2, 0.92894 is obtained for November and a minimum value of 0.10886 is obtained for March. The minimum Se/SD percentage value for the same was obtained as 22.1 for June.

When the runoff of a month and rainfall of same and preceding four months

Table 14.

Month	No.of Months considered	Models Developed for Kuttippuram River Guage Station	R2 Value	S.D.	Std Error	Se/SD (%)
January	1	$R_m=65.457+0.9109P_m$	0.1847	35.585	16.3212	45.86
	2	$R_m=1.08922+0.52629P_m-0.61823P_{m-1}$	0.58485	27.711	19.2603	70.8
	3	$R_m=66.91643+0.83854P_m-0.80949P_{m-1}+0.30952P_{m-2}$	0.64191	28.193	19.0904	67.77
	4	$R_m=66.73885+0.83437P_m-0.80804P_{m-1}+0.30565P_{m-2}+0.00302P_{m-3}$	0.64192	31.520	19.0987	60.59
	5	$R_m=78.25157+0.69744P_m-0.72105P_{m-1}+0.21221P_{m-2}+0.00717P_{m-3}-0.030642P_{m-4}$	0.64479	36.250	19.0564	52.57
	6	$R_m=225.44346+0.55841P_m-1.63456P_{m-1}+1.29262P_{m-2}-0.42097P_{m-3}+0.16192P_{m-4}-0.51003P_{m-5}$	0.76596	36.038	26.9819	74.87
	7	$R_m=319.16+1.31P_m-0.543P_{m-1}-1.009P_{m-2}+0.42P_{m-3}-0.002P_{m-4}+0.095P_{m-5}-0.614P_{m-6}$	0.978	15.53	5.80488	37.38

(Table 14. Contd......)

February	1	R_m=31.343068-0.482P_m	0.02035	19.204	6.08761	31.69
	2	R_m=27.2323-0.43987P_m +0.41988P_{m-1}	0.18204	18.76	8.003745	42.67
	3	R_m=32.93523+1.04612P_m +0.27583P_{m-1} - 0.32244P_{m-2}	0.39333	18.688	9.905908	52.9
	4	R_m=19.09291+1.45588P_m +0.44016P_{m-1} - 0.46972P_{m-2}+0.17135P_{m-3}	0.45385	19.824	10.08473	50.9
	5	R_m=29.1346+1.78859P_m +0.71799P_{m-1} - 0.60618P_{m-2} +0.43626P_{m-3}-0.19572 P_{m-4}	0.62662	8.9281	9.80803	51.8
	6	R_m=21.21793+1.80275P_m +0.81211 P_{m-1} -0.66751P_m -2+0.50094P_m -3-0.19875 P_{m-4} +0.027078P_{m-5}	0.63177	23.029	9.570364	41
	7	Rm=193.71177+5.24P_m +0.893P_m -1-2.3 P_{m-2} +2.097P_{m-3} -.789P_{m-4}+0.27P_{m-5} - 0.649P_{m-6}	0.988	5.8706	2.251195	38.3
March	1	R_m=-0.0876P_m +14.467	0.0163	12.878	0.513832	3.98
	2	R_m=14.4003-0.981P_m +0.06519P_{m-1}	0.01688	13.763	1.787909	12.1
	3	R_m=12.9981+0.03248P_m -0.33381 P_{m-1} +0.19973P_{m-2}	0.10274	14.613	3.958599	27.1
	4	R_m=12.82537+0.07772P_m -0.19625P_{m-1} +0.2028P_{m-2} -0.4235P_{m-3}	0.10886	16.282	15.58302	95.7
	5	R_m=-10.80373+.48943P_m +0.28224P_{m-1} +0.3348P_{m-2} .0.37004P_{m-3} +0.23697P_{m-4}	0.22601	17.521	5.453379	31
	6	R_m=-7.19649+0.68094P_m +0.75486P_{m-1} +0.934442P_{m-2} -0.63061P_{m-3} +0.58797P_{m-4} -0.21195P_{m-5}	0.70129	13.331	5.968144	44
	7	R_m=-49.34966-4.474P_{m-2}.15P_{m-1} +0,46P_{m-2} +.75P_{m-3} +0.5P_{m-4}-0.13P_{m-5}+0.6P_{m-6}	0.76967	16.556	5.5280	33

(Table 14. Contd..........)

April	1	$R_m=0.1489P_m-0.6443$	0.6586	6.13839	5.27431	85
	2	$R_m=0.49086+0.18125P_m-0.18098P_{m-1}$	0.73395	5.7933	4.8819	84
	3	$R_m=-0.023821+0.17453P_m-0.24037P_{m-1}+0.44399P_{m-2}$	0.76713	6.3364	4.6903	74
	4	$R_m=-1.41459+0.14007Pm-0.1196P_{m-1}+0.41654P_{m-2}+0.16414P_{m-3}$	0.81303	6.3478	4.326	68
	5	$R_m=0.99057+0.01399P_m-0.12159P_{m-1}-0.24117P_{m-2}+.35484P_{m-3}+0.24305P_{m-4}$	0.88385	5.7772	3.556	61
	6	$R_m=1.17832+0.0142P_m-0.12503P_{m-1}-.24429P_{m-2}+0.352854P_{m-3}+0.2454P_{m-4}-0.00192P_{m-5}$	0.88386	7.0752	3.552	49.5
	7	$R_m=3.23394+0.58309P_m-0.29195P_{m-1}+2.28061P_{m-2}-0.09315P_{m-3}-0.80875P_{m-4}+0.37861P_{m-5}-0.27292P_{m-6}$	0.91171	8.7243	3.1484	36
May	1	$R_m=0.537P_m-17.732$	0.8353	19.825	7.4022	87.8
	2	$R_m=-13.124+0.555P_m-0.097P_{m-1}$	0.8473	20.403	5.9643	78
	3	$R_m=-8.784+0.571P_m-0.148P_{m-1}+0.332P_{m-2}$	0.8914	20.1596	6.9778	84
	4	$R_m=-12.565+0.607Pm-0.193P_{m-1}-0.082P_{m-2}+1.203P_{m-3}$	0.9009	21.5317	5.4488	71
	5	$R_m=-14.731+0.596P_m-0.263P_{m-1}+0.19P_{m-2}+1.042P_{m-3}+0.372P_{m-4}$	0.91153	23.4912	14.7004	62.6
	6	$R_m=-18.179+0.573P_m+0.027P_{m-1}+0.209P_{m-2}+2.3P_{m-3}-0.028P_{m-4}-0.5304P_{m-5}$	0.92615	23.2865	3.5219	51.4
	7	$R_m=-36.36+0.58P_m+1.966P_{m-1}+0.534P_{m-2}+2.6P_{m-3}+0.26P_{m-4}-0.75P_{m-5}+0.183P_{m-6}$	0.930	36.07	11.8104	32

(Table 14. Contd......)

June	1	$R_m=-31.559+1.038P_m$	0.5929	124.463	5.2915	76
	2	$R_m=-221.43257+1.22336P_m-1.03405P_{m-1}.$	0.76784	100.478	28.9533	28
	3	$R_m=-220.83837+1.24731P_m+1.09441P_{m-1}-0.2616P_{m-2}.$	0.77305	107.306	76.9982	71
	4	$R_m=-295.91854+1.34614P_m+1.27644P_{m-1}-0.88992P_{m-2}+2.95343P_{m-3}.$	0.82542	103.436	23.1336	22
	5	$R_m=-261.41617+1.33094P_m+0.97512P_{m-1}-0.48204P_{m-2}+3.37349P_{m-3}+9.19031P_{m-4}.$	0.85972	103.323	5.0725	63
	6	$R_m=-527.10409+1.95107P_m+1.70926P_{m-1}+0.32264P_{m-2}-0.74658P_{m-3}-4.2443P_{m-4}-7.86516P_{m-5}.$	0.988	34.8963	12.463	35
	7	$R_m=-452.32316+1.74432P_m+1.4541P_{m-1}+0.84162P_{m-2}-0.277P_{m-3}-1.9266P_{m-4}-6.94P_{m-5}-0.94P_{m-6}.$	0.998	23.2657	2.51499	11
July	1	$R_m=1.0303P_m+268.3.$	0.5761	214.2783	204.2783	95
	2	$R_m=401.19752+1.13018P_m-0.41532P_{m-1}.$	0.60401	221.396	207.0973	95
	3	$R_m=250.24012+1.1859P_m-0.31577P_{m-1}+0.7651P_{m-2}.$	0.63625	229.1947	198.4885	86
	4	$R_m=236.91882+1.24456P_m-0.19189P_{m-1}+1.19553P_{m-2}-3.71891P_{m-3}.$	0.71367	222.754	176.1018	79
	5	$R_m=166.19191+1.2699P_m-0.12061P_{m-1}+1.36896P_{m-2}-2.27006P_{m-3}+2.5243P_{m-4}.$	0.62654	243.383	172.1019	70
	6	$R_m=113.6557+1.34718P_m-0.14371P_{m-1}+1.66634P_{m-2}-2.6627P_{m-3}+2.08061P_{m-4}+7.10779P_{m-5}.$	0.7315	278.478	170.5326	61
	7	$R_m=359.137+1.85P_m-1.45P_{m-1}+1.28P_{m-2}-5.29P_{m-3}+9.81P_{m-4}+13.74P_{m-5}+14.05P_{m-6}.$	0.8054	290.3595	264.7649	91

(Table 14. Contd.......)

August	1	$R_m=3.6129P_m -529.64.$	0.4623	285.4573	215.4573	75.5
	2	$R_m-764.28735+3.52912P_m -0.41532P_{m-1}.$	0.56921	273.151	234.458	85
	3	$R_m=-366.33104+3.03598P_m +0.69993P_{m-1} -0.69521P_{m-2}.$	0.61656	278.3498	241.058	86
	4	$R_m=-602.09613+3.2294P_m +0.74517P_{m-1} -0.54949P_{m-2} +0.79802P_{m-3}.$	0.64051	295.2421	233.409	79
	5	$R_m=-563.35476+3.10858P_m +0.81574P_{m-1} -0.44309P_{m-2} +1.24643P_{m-3} -1.87956P_{m-4}.$	0.70625	298.3842	210.99	70.7
	6	$R_m=-1692.44678+4.94162P_m +0.82736P_{m-1} +0.30901P_{m-2}+2.32786P_{m-3} -4.20671P_{m-4} +11.48217Pm-5.$	0.80118	283.4559	173.581	61.2
	7	$R_m=-3291.806+7.59P_m+1.021P_{m-1} +0.8792\ P_{m-2} +5.1162P_{m-3} -0.81323P_{m-4} -10.055P_{m-5} +50.913P_{m-6}.$	0.79286	480.3988	326.542	68
Sept	1	$R_m=1.8104P_m +44.57.$	0.7324	134.8015	104.8015	77
	2	$R_m=-29.16731+1.77533P_m +0.23218P_{m-1}.$	0.73634	143.03	133.793	94
	3	$R_m=-171.52901+1.94798P_m +0.10677P_{m-1} +0.32508P_{m-2}.$	0.82318	127.1592	110.1231	86
	4	$R_m=-91.81688+1.85063Pm+0.0582P_{m-1} +0.34511P_{m-2} -0.1298P_{m-3}.$	0.82322	138.1774	109.533	79.4
	5	$R_m=-398.73734+2.154P_m +0.20681P_{m-1} +0.36613P_{m-2} +0.1786P_{m-3} +0.57921P_{m-4}.$	0.84243	146.2725	103.4303	70.7
	6	$R_m=-702.0711+2.683P_m +0.21083P_{m-1} +0.4152P_{m-2} -0.66825P_{m-3} +1.22694P_{m-4} -1.37024P_{m-5}.$	0.901187	133.291	81.628	61
	7	$R_m=-2371.65524+3.80347P_m +1.95417P_{m-1} +0.446P_{m-2} +2.23P_{m-3} +3.01P_{m-4} -4.08P_{m-5} +9.98P_{m-6}.$	0.998	21.737	10.9186	34

(Table 14. Contd.......

Oct	1	$R_m=1.4676P_m+44.345$	0.2706	133.484	120.2684	90.1
	2	$R_m= 115.71638+1.898P_m+0.51411P_{m-1}$	0.39598	136.457	127.6447	93.5
	3	$R_m= 64.14145+1.75513P_m+0.55892P_{m-1} -0.47423P_{m-2}$	0.43569	142.464	123.4346	86.6
	4	$R_m=8.96335+1.61205P_m+0.6695P_{m-1} -0.59582P_{m-2}+0.25162P_{m-3.}$	0.56186	137.512	108.7134	79.1
	5	$R_m=362.0593+1.92895P_m+1.05152P_{m-1} -0.37055P_{m-2}+0.17362P_{m-3}+0.44758P_{m-4}$	0.60694	145.619	102.9687	71
	6	$R_m=39.46267+2.19079P_m+0.71658P_{m-1} -0.50571P_{m-2}+0.12661P_{m-3}+0.08397P_{m-4} -0.80813P_{m-5}$	0.69553	147.991	90.62581	61
	7	$R_m=45.5301+0.77P_m+0.985P_{m-1}-0.83P_{m-2} +0.29P_m-3+0.43P_m-4+0.199P_m-5-1.58P_{m-6}$	0.74177	166.92	83.4647	50
Nov	1	$R_m=2.1005P_m+47.743$	0.5110	100.52	93.56	93
	2	$R_m=-107.41775+1.13815P_m+1.41058P_{m-1}$	0.71124	85.07	79.578	94
	3	$R_m=-252.6162+1.13973P_m+1.80022P_{m-1} +0.646635P_{m-2}$	0.83814	68.796	59.579	86
	4	$R_m=-569.07099+0.21436P_m+2.52787P_{m-1} +0.386202P_{m-2}+0.8458P_{m-3}$	0.92894	49.934	39.477	79
	5	$R_m=-610.25812+0.1842P_m+2.47485P_{m-1} +0.44087P_{m-2}+0.79579P_m-3+0.12529P_{m-4}$	0.96862	37.099	26.239	71
	6	$R_m=-674.90945+0.17176P_m+2.53855P_{m-1} +0.50849P_{m-2}+0.84062P_{m-3}+0.11345P_{m-4} +0.079P_{m-5}$	0.970397	41.625	25.490	61
	7	$R_m=-593.23-0.132P_m+2.84P_{m-1}+0.37P_{m-2} +0.905P_{m-3}+0.09P_{m-4}-0.06P_{m-5} -0.327P_{m-6}$	0.984	37.33	32.249	86

(Table 14. Contd......)

Dec	1	$R_m=1.0683P_m+75.752$	0.4221	52.82840.1	52.488	99
	2	$R_m=14.41431+0.5718P_m+0.8129P_{m-1}$	0.68705	57	37.563	93
	3	$R_m=-28.59694+0.65402P_m+0.51197P_{m-1}+0.39601P_{m-2}$	0.76167	37.845	32.775	86
	4	$R_m=-80.45639+0.33264P_m+0.65834P_{m-1}+0.50013P_{m-2}+0.17435P_{m-3}$	0.81738	36.296	28.695	79
	5	$R_m=33.11907-P.18215P_m+1.30321P_{m-1}+0.19321P_{m-2}+0.30922P_{m-3}-0.37574P_{m-4}$	0.85385	36.302	35.959	99
	6	$R_m=59.05211-0.3633P_m+1.47359P_{m-1}+0.14197P_{m-2}+0.34215P_{m-3}-0.44393P_{m-4}-0.02096P_{m-5}$	0.85649	41.538	25.437	61
	7	$R_m=-162.76683-0.267P_m+1.34445P_{m-1}+0.37986P_{m-2}+0.54191P_{m-3}-0.26012P_{m-4}-0.0604P_{m-5}+0.25889P_{m-6}$	0.94601	31.203	50.602	66

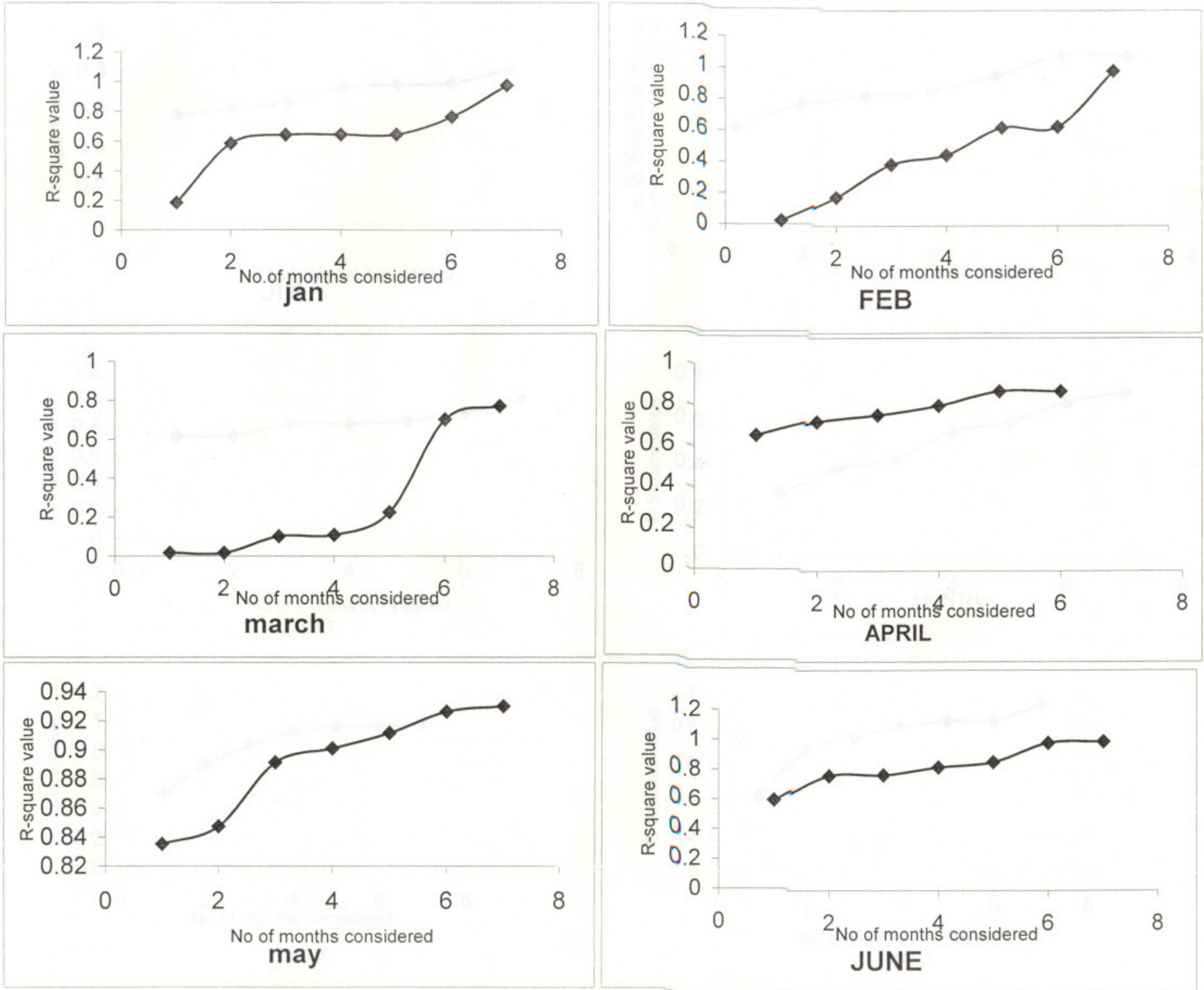
jan
R-square value
No.of months considered
FEB
R-square value
No of months considered
march
R-square value
No of months considered
APRIL
R-square value
No of months considered
may
R-square value
No of months considered
JUNE
R-square value
No of months considered

Fig.9

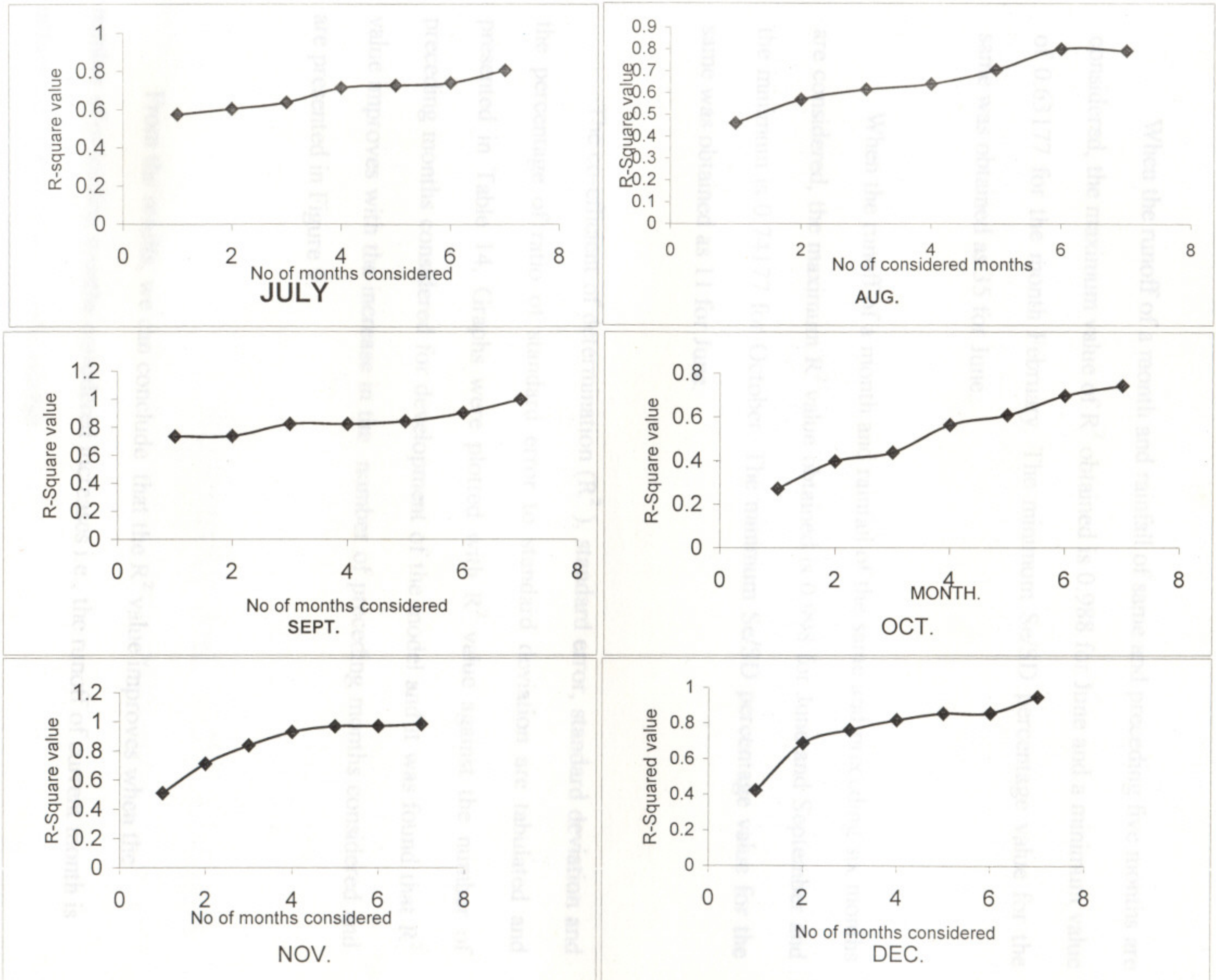
R-square value
No of months considered
JULY
R-Square value
No of considered months
AUG.
R-Square value
No of months considered
SEPT.
R-Square value
MONTH.
OCT.
R-Square value
No of months considered
NOV.
R-Squared value
No of months considered
DEC.

FIG.9.contd.......

are considered for developing the model, the maximum R^2 value obtained is 0.96862 for November and the minimum is 0.22601 for March. The minimum Se/SD percentage value for the same was obtained as 63.2 for June.

When the runoff of a month and rainfall of same and preceding five months are considered, the maximum value of R^2 obtained is 0.988 for June and a minimum value of 0.63177 for the month February. The minimum Se/SD percentage value for the same was obtained as 35 for June.

When the runoff of a month and rainfall of the same and preceding six months are considered, the maximum R^2 value obtained is 0.998 for June and September and the minimum is 0.74177 for October. The minimum Se/SD percentage value for the same was obtained as 11 for June.

The co-efficient of determination (R^2), standard error, standard deviation and the percentage of ratio of standard error to standard deviation are tabulated and presented in Table 14. Graphs were plotted with R^2 value against the number of preceding months considered for development of the model and it was found that R^2 value improves with the increase in the number of preceding months considered and are presented in Figure 9.

SUMMARY AND CONCLUSION

From the results, we can conclude that the R^2 value improves when the number of preceding months considered increases i.e., the runoff of current month is influenced by preceding months rainfall.

SUMMARY AND CONCLUSION

The calculation of runoff volume is of greater importance in all water resources development studies. In the present work,a comprehensive study of the Bharathapuzha river basin with a view to establish and model the rainfall-runoff process was done. The monthly rainfall and runoff datas were collected from the Irigation department.

The monthly runoff and rainfall values were correlated and that a significant correlation was found between the runoff and rainfall.

Runoff predicting equations were developed by linear and multiple regression methods. The standard error, standard deviation, co-efficient of determination (R^2) and the percentage of ratio of standard error to standard deviation in each case were found out. Multiple regression equations to predict the runoff in a particular month were developed with the rainfall values of different numbers of preceding months as independent variables. The co-efficient of determination values for these equations showed that the accuracy of prediction can be increased to a certain extent by taking rainfall values of more numbers of preceding months as input to the model.

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Appendix

Location:Kuttipuram.

RUNOFF (Mm^3)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE.	JULY.	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	65.93	35.5	13.69	29.34	47	998.08	2262.83	984.53	344.66	688.59	291.01	96.58
1981	24.97	7.03	1.58	3.8	18.78	1295.16	999.47	1555.21	911.38	366.01	228.52	45.66
1982	39.46	18.48	0.92	4.92	20.62	596.61	878.93	1292.03	187.77	179.37	185.34	36.49
1983	51.52	19.36	4.5	0	2.96	100.93	1136.37	1261.43	874.4	399.11	383.39	135
1984	24.93	15.72	7.73	7.32	4.04	474.82	870.57	284.94	110.94	227.77	35.87	40.27
1985	108.81	52.46	29.23	27.63	35.96	522.72	577.09	348.05	155.15	205.21	130.84	102.62
1986	101.86	48.72	10.54	5.62	37.38	336.55	360.54	592.45	232.48	263.11	280.78	135.31
1987	119.35	61.44	38.85	0.87	59.53	216.61	348.61	326.9	252.47	319.49	331.17	223.06
1988	20.25	5.78	9.82	26.18	26.64	238.12	528.04	681.17	591.11	125.06	29.82	16.6
1989	79.29	25.99	17.57	4.26	41.42	532.02	807.48	662.04	545.69	657.55	320.59	134.66
1990	85.67	26.8	4.45	3.52	158.59	559.3	861.81	627.19	190.22	216.1	327.58	83.02
1991	108.94	19.56	5.17	12.32	2.49	630.95	1279.61	1005.49	308.82	399.99	413.63	152.48

RAINFALL (mm)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE.	JULY.	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	0	0	16.64	75.4	148.3	645.03	671.72	307.26	141.68	247.9	125.7	16.75
1982	0	0	16.64	35.19	116.3	450.53	424.68	416.3	49.87	139.9	97.92	4.54
1983	0	0	0	0.88	83.19	242.64	472.52	415.06	375.1	170.2	86.51	57.47
1984	1.27	14.3	44.45	74.7	31.02	528.01	510.54	243.42	93.3	140.1	37.86	21.81
1985	54.95	5.36	2.28	99.36	88.63	674.1	381.23	310.15	95.6	160.86	79	25.23
1986	3.43	9.08	4.98	34.29	62.71	421.04	315.05	427.58	151.06	166.31	117.45	5.94
1987	0.23	0.45	10.8	13.75	92.48	316.9	277.4	314.85	226.9	209.9	172.83	128.25
1988	0	10.24	47.25	187.83	127.12	287.3	429.7	373.73	345.87	61.34	27	13.66
1989	2.78	0	36.27	47.95	98.4	480.43	524.53	245.58	176.5	215.57	54.7	6.57
1990	23.3	0	13.63	94.79	311.41	372.55	391.2	301.13	71.64	259.3	103.42	9.22
1991	7.91	0.19	5.2	76.53	43.64	585.11	1093	378.3	73.15	213.62	157.16	1.71

Location:Cheruthuruthy.

RUNOFF. (Mm^3)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	48.49	24.96	9.63	14.49	31.5	590.33	1288.31	569.92	153.64	412.39	170.61	16.93
1981	22.63	8.76	8	9.25	20.31	659.8	484.19	835.99	463.61	185.44	88.61	23.43
1982	27.16	14.78	8.04	10.09	15.51	325.11	451.28	744.77	63.66	95.55	95.41	18.12
1983	22.47	4.23				36.87	562.2	781.21	440.6	233.79	198.83	90.69
1984	24.41	18.88	8.92	9.13	0.55	184.46	384.57	71.09	71.38	89.25	43.47	39.02
1985	47.72	9.18	1.26	4.2	4.86	210.24	306.51	194.39	47.8	62.74	25.59	19.7
1986	32.59	17.2	4.97	0.22	3.71	136.59	179.74	272.66	87.55	87.01	77.47	34.15
1987	60.13	21.63	8.56	1.86	10.37	87.13	180.87	70.22	115.08	188.86	165.25	133.47
1988	8.66	2.65	3.86	31.48	7.95	120.45	179.4	243.76	244.99	42.42	6.22	8.47
1989	20.34	4.31	6.66	1.64	2.2	206.55	318.55	251.57	168.38	194.63	62	30.76
1990	30.78	2.14			13.8	209.18	423.39	263.03	28.38	77.32	119.34	16.83
1991	48.17	2.5	0	0	0	202.52	502.42	321.73	72.76	111.55	129.63	20.19

RAINFALL (mm)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	0	0	23.82	69.72	157.42	595.35	618.16	274.22	136.27	221.75	164.93	8.44
1982	0	0	13.76	35.37	112.44	410.23	415.97	424.96	47.55	181.72	102.35	5.07
1983	0	0	0.08	1.43	81.78	254.56	447.03	396.83	246.85	173.31	81.37	61.98
1984	0.71	13.02	48.86	65.08	26.76	458.08	471.87	247.87	87.88	181.39	37.08	21.28
1985	53.57	6.32	2.7	74.15	79.42	641.75	357.7	314.36	92.92	143.65	71.59	24.16
1986	2.78	9.66	2.8	29.73	57.11	417.24	328.75	419.95	136	163.43	93.86	7.36
1987	0.27	0.37	12.12	13.1	91.62	295.22	282.22	317.35	134.35	209.78	164.74	142.16
1988	0	7.15	51.7	188.66	104.6	230.54	410.62	339.68	322.93	55.76	28.64	23.24
1989	3.31	0	38.89	49.32	100.78	432.89	555.11	245.58	166.47	188.07	56.9	7.79
1990	12.05	0	14.58	66.96	274.37	374.39	459.85	339.4	37.59	243.49	103.74	8.77
1991	7.85	0.29	5.93	110.69	38.34	571.84	833.61	362.7	55.16	186.1	80.11	2.11

Location:Pampady.

RUNOFF. (Mm^3)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	41.93	12.43	4.78	6.9	22.83	180.23	339.03	213.82	108.71	191.09	152.61	60.83
1981	15.97	1.8	1.05	1.34	14.66	211.19	169.95	300.98	196.59	122.48	78.15	24.31
1982	19.83	7.44	4.91	5.39	8.06	102.83	150.21	225.68	74	84.76	86.64	53.89
1983	20.26	5.64	1.37	0.76	7.45	34.9	141.53	144.99	60.23	50.14	57.75	35.96
1984	24.48	20.39	16.67	15.02	4.57	92.87	139.34	64.25	28.62	61.99	24.29	28.49
1985	11.57	2.36	0.31	0.89	1.09	117.99	52.55	27.69	6.28	10.52	7.27	3.56
1986	3.1	0.86	0.08		0.13	51.23	44.9	135.26	7.6	12.31	11.35	3.77
1987	27.33	2.73				33.13	86.54	72.16	53.35	89.67	78.87	136.09
1988	14.68	3.29	5.49	13.36	22.95	36	78.19	126.43	59.21	27.37	15.42	7.96
1989	11.98	0.55	0.84		3.84	63.48	151.8	82.49	53.16	61.15	31.85	25.05
1990					7.71	81.07	158.44	99.53	23.98	59.64	65.23	
1991	17.72	4.11	0	0	0	55.11	271.84	165.26	60.04	92.16	97.11	59.63

RAINFALL (mm)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	0	0	32.94	72.59	151.83	476.14	460.05	228.29	130.82	203.21	127.37	4.53
1982	0	0	14.54	24.58	139.78	357.87	380.4	337.82	61.73	147.03	110.74	0.72
1983	0	0	0	1.8	54.78	189.3	264.61	300.1	169.13	153.71	83.5	58.26
1984	1	14.02	46.38	43.56	23.56	418.63	394.12	194.36	70.06	181.02	30.08	25.11
1985	47.72	4.44	2.78	104.33	70.57	456.49	271.96	262.38	102.74	154.53	98.11	37.33
1986	2.55	3.92	2.88	20.7	57.5	350.13	243.06	358.38	95.19	146	58.48	9.52
1987	0.22	0.22	22.01	14.6	83.49	183.58	175.8	235.03	112.06	187.58	109.67	145.23
1988	0	4.03	47.44	179.19	19.8	155.48	340.41	267.44	209.49	46.71	35.66	9.02
1989	6.22	0	36.54	61.39	120	391.44	444.25	188.6	171.5	246.15	93.72	20.03
1990	58.38	0	41.56	65.62	232.88	305.73	287.56	262.2	30.4	243.03	102.73	8.91
1991	6.83	0	11.17	49.67	27.2	394.47	725.65	217.83	70.55	128.42	80.9	0

Location:Thrithala.

RUNOFF (Mm^3)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	0CT.	NOV.	DEC.
1980	162.46	34.99	1.39	3.19	21.33	651.85	1339.68	667.06	146.29	477.47	165.67	7.76
1981	6.01	4.85	4.82	9.68	29.88	780	604.93	934.76	524.38	190.62	125.67	19.22
1982	28.6	22.7	12.39	7.77	12.81	417.82	561.89	833.32	479.73	129.65	189.41	20.26
1983	0.66					39.1	848.76	868.32	480.41	251.69	255.31	106.68
1984	11.65	2.31	0.84	1.04	0.79	233.77	484.24	128.26	35.86	93.03	19.53	5.59
1985	96.2	18.43	3.34	4.72	2.91	274.21	381.03	200.75	50.53	73.19	20.64	20.5
1986	47.87	11.06			7.03	152.98	186.22	305.58	93.23	95.93	92.16	35.79
1987	19.09	3.75				65.84	253.38	173.63	120.01	107.57	206.88	77.42
1988	37.87	4.15	9.16	36.68	43.34	132.29	243.93	231.2	251.86	40.56	24.18	24.15
1989	18.76	0.48	2.74	0.13	2.9	223.65	403.89	260.38	181.43	219.03	85.61	24.53
1990	42.16	0.67			30.29	271.45	473.84	319.77	54.72	84.43	171.82	41.98
1991	38.27	5.06	0	2.97	0	274.03	747.93	604.14	73.97	135.55	160.55	22.62

RAINFALL (mm)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	0CT.	NOV.	DEC.
1980	0	0	20.4	73.65	128.67	624.35	661.49	297.17	135.55	233.67	132.9	13.03
1982	0	0	12.4	37.9	120.38	442.1	429.1	438.5	49.13	156.17	100.72	4.5
1983	0	0	0.07	1.28	85.71	235.78	443.5	415.42	270.75	187.3	80.22	58.63
1984	1.36	13.4	50.06	66.76	29	471.05	492.46	246.9	89.72	191.8	27.36	21.35
1985	55.7	6.1	43.38	74	81.98	595.7	368.42	312.66	100.35	159.68	88.3	22.56
1986	3.74	9.3	4.19	30.25	55.36	320.38	325	416.07	142.13	162.4	107.28	6.23
1987	0.24	0.4	12.34	12.06	90.99	315.94	290.23	317.26	132.36	214.05	170.23	136.01
1988	0	9.05	46.83	181.64	111.66	281.3	432	318.78	354.7	59.3	29	15.38
1989	2.97	0	37.73	48.99	98.97	470.22	541.6	240.93	172.42	211.9	57.95	6.99
1990	25.55	0	35.99	88.72	289.27	394.04	440.67	336.36	45.96	253.15	110.42	15.66
1991	7.39	0.25	5.6	74.55	41.95	570.86	848.33	380.46	52.93	203.06	84.43	1.78

Location:Thiruvegapura.

RUNOFF (Mm^3)

YEAR.	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	7.37	1.34		2.67	4.48	348.26	826.25	295.72	89.02	233.02	55.44	21.34
1981	10.45	2.99	0.94	1.49	8.15	481.89	373.32	580.07	377.87	175.31	97.28	21.12
1982	12.43	3.64			5.27	123.9	251.02	470	67.61	43.31	54.03	10.38
1983	6.65	2.09				48.05	250.03	363.58	302.46	148.86	98.36	22.04
1984	8.3	4.97	0.47	2.17	1.35	198.94	346.91	156.95	366.22	131.61	26.94	16.16
1985	17.44	3.68	0.02	1.44	7.9	213.17	165.4	146.56	57.75	122.27	29.68	11.85
1986	4.7	0.3		0.29	1.32	152.02	173.95	263.94	122.71	152.32	160.93	29.76
1987	10.54					44.09	51.27	93.99	76.7	135.67	112.23	41.89
1988	12.28		5.13	98.54	18.66	107.52	226.2	219.86	251.64	41.95	27.39	13.14
1989	1.27				0.27	185.38	398.56	265.94	276.26	362.54	144.22	24.28
1990	2.76				45.29	153.12	349.81	225.66	55.19	53.86	77.23	5.46
1991	0.88	0	0	0	0	240.28	444.18	328.61	101.6	163.69	149.14	30.44

RAINFALL (mm)

YEAR.	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	0	0	18.96	92.26	126.18	946.98	899.74	484.88	181.4	382.5	87.28	34.62
1982	0	0	14.14	33.82	124.35	436.86	474	381.15	82.86	104.36	116.8	4.81
1983	0	0	0	0.625	64.83	524.1	578.5	588.5	433.7	164.98	131.9	47
1984	0	30.5	24.23	134.47	51.27	873.1	683.9	206.6	128.9	298	9.3	8.8
1985	43.85	0	0	68.38	116.63	806.98	513.1	241.4	234.9	272	26.1	28.2
1986	0	0	7.3	38.2	119.1	295.2	253	270	158.4	149.2	248.2	39
1987	2.47	5.47	11.87	57.1	131.27	619.67	228.7	468.4	203.1	202.4	215.33	0
1988	0	28.1	53.45	252.3	175.15	498.8	472.55	378.8	497.45	94.1	1.5	17.2
1989	0	0	24	22	95.6	628.5	492	237.5	235.5	409.5	39.5	0.5
1990	2.8	0	0	57.55	352.6	400.1	542.6	295.2	34.1	280.7	100.13	9.33
1991	14.3	0	0	100.5	67.95	756.15	785.8	352.3	318.4	315.6	107.5	0

Location:Cheerakuzhy.

RUNOFF(Mm^3)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	7.51	2.86	-	-	-	-	-	-	5.41	4.45	7.58	7.55
1981	16.19	3.89	-	-	38.74	440.08	282.16	189.03	2.51	7.44	7.4	8.33
1982	4.65	2.7	-	8.89	25.45	0	190.62	289.91	36.89	38.45	52	10.95
1983	11.39	1	-	-	1.96	16.62	432.9	322.78	158.86	44.78	56.68	29.06
1984	14.73	9.05	3.77	-	-	157.23	382.71	211.44	29.21	117.95	16.94	18.13
1985	36.7	1.92	-	-	-	-	-	-	22.76	49.94	17.76	12.67
1986	-	-	-	-	-	-	-	-	7.55	7.75	6.52	9.26
1987	14.178	0.52	-	-	-	9.328	115.086	15.432	19.721	33.687	34.566	42.082
1988	13.966	1.198	7.906	30.995	12.127	57.501	129.293	262.8	190.927	26.484	21.638	15.168
1989	7.48	-	-	-	-	347.57	427.39	176.43	96.08	200.25	16.62	10.51
1990	9.894	0.06	-	-	19.298	351.09	512.35	191.858	49.358	40.304	95.616	13.927
1991	25.904	0.446	-	-		743.05	861.446	498.76	21.617	25.068	25.82	14.746

RAINFALL (mm)

YEAR	JAN.	FEB.	MAR.	APR.	MAY.	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	0	0	21.43	67.17	116.46	632.56	696.31	313.93	108.46	244.62	132.02	5.33
1982	0	0	14.44	38.03	87.88	458.7	450.03	556.39	34.03	182.06	111.44	10.93
1983	0	0	0	2.41	102.29	254.94	504.62	410.51	291.58	176.74	88.02	63.81
1984	0.3	10.97	48.68	81.1	33.2	462.36	490.89	278.17	87.31	135.8	35.14	24.82
1985	56.63	11.65	2.71	62.14	74.86	640.82	382.73	341.68	58.82	93.26	59.51	10.93
1986	3.93	16.92	0.79	36.92	53.38	470.26	365	421.14	142.6	165.53	101	3.15
1987	0.5	0.49	7.19	10.68	74.7	315.82	267.5	324.42	135.45	175.15	167.11	149.11
1988	0	5.49	37.4	151.58	66.67	206.09	428.07	373.35	353.64	45.9	26.79	17.16
1989	0.695	0	38.75	33.52	96.07	437	521.78	287.83	163.45	187.69	27.8	0.5
1990	14.29	0	2.9	55.11	300.05	433.84	465.61	391.32	36.14	259.83	116.8	5.3
1991	3.53	0.75	2.14	88.42	48.11	553.96	820.89	492.28	38.6	175.54	58.5	3.2

RAINFALL-RUNOFF MODELLING IN THE BHARATHAPUZHA RIVER BASIN

BY

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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY
in
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ABSTRACT

A comprehensive study of the Bharathapuzha river basin with a view to establish and model the rain fall-runoff process was done. It was found that there exists a significant correlation between runoff and rainfall. Runoff predicting equations were developed by linear and multiple regression methods. The standard error, standard deviation, co-efficient of determination (R^2) and the percentage of ratio of standard error to standard deviation in each case were found out. Multiple regression equations to predict the runoff in a particular month were developed with the rainfall values of different numbers of preceding months as independent variables. The co-efficient of determination values for these equations showed that the accuracy of predicition can be increased to a certain extent by taking rainfall values of more numbers of preceding months as input to the model.