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RAINFALL-RUNOFF MODEL FOR SILENT VALLEY CATCHMENT OF NILGIRI BIOSPHERE RESERVE

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An attempt has been made to study the rainfall-runoff relationship in the Silent Valley catchment of the Kunthipuzha sub-basin of Bharathapuzha. The data available for modeling were the rainfall and runoff data for a period of 16 years of which 13 years data were used for calibration, and the remaining three years for verification of the model. A simple regression model for monthly rainfall-runoff simulation in the basin was developed and the results are presented here. The monthly rainfall-runoff regression equation was linear. The historical monthly means and standard deviations of the flows are preserved by the model. The memory parameter n is a characteristic of the month which controls the memory of the rainfall-runoff processes. It is equal to 1 for months with delayed runoff and zero otherwise. The coefficients of the model are regionalized so that the model may also be used at ungauged sites. The coefficients are estimated by the least squares. The correlation coefficient and monthly runoff coefficients of the basin are presented. The model efficiency in terms of the variance of the predictand explained is 91%.

Key Words : Rainfall-Runoff Model; Runoff Coefficient; Regression; Memory Parameter

Introduction

The type of rainfall-runoff model which is suitable for any purpose depends on different factors, such as, (1) time scale of modeling (2) measurements of physical parameters of the basin, (3) reliability and type (conventional or automatic) of data from the hydrometeorological network of the basin, (4) specific use of the model and the purpose of research and (5) available computing facilities. Experience has shown that when the time scale of modeling is long enough, say one month or longer, simple models are often adequate to represent the relation between rainfall and runoff without considering the details of various intervening factors (Fleming[1], Todini and Wallis[2]). The availability of data is a major problem for the widespread application of rainfall-runoff models. Considering the availability of data from the Silent Valley catchment, a simple regression model developed by Mimikovu and Rao[3] for monthly rainfall-runoff simulation has been attempted. This model requires only monthly rainfall and runoff as input. According to them simplicity in rainfall-runoff models does not necessarily mean that the models may be inaccurate, especially in models of monthly flow.

Methodology

The model, which can be used to simulate flows with linear monthly rainfall-runoff behaviour (Mimikovu and Rao[3]), is explained below.

$$Q_{p,t} = a_{t,o} + a_{t,1}\left[\frac{P_{p,t} + P_{p,(t-1)} \ldots + P_{p,(t-n)}}{n+1}\right] \quad \ldots(1)$$

where $Q_{p,t}$ (m^3/sec) = the discharge of the pth year(p = 1, 2,...p,...N) and the t th month (t =1,2,...m) of the N-year record of m months;

$P_{p,t}$ (mm) = the corresponding monthly mean areal rainfall;

n = the memory parameter of the model; and

$a_{t,o}$, $a_{t,1}$ = the coefficients of the model.

In cases with significant scattering of monthly rainfall-runoff pairs along the regression line, eq. (i) indicates a way of improving the relationships by using the memory parameter n. The pairwise monthly regression of the variables is replaced by the regression of the dependent variable $Q_{p,t}$ at month t to an average value of the independent variable $P_{p,t}$ during months t, t-1... t-n, with n indicating the memory of the process at month t. Thus the monthly regression is significantly improved. The value of n is selected such that the relation between dependent and independent variables in eq. (1) gives the maximum correlation coefficient. The value of n is varied from 0 to 3. In cases when the monthly regression does not improve after the operation, the model of eq. (1) is apparently not applicable. After estimating the parameter n the coefficients $a_{t,o}$ and $a_{t,1}$ must be estimated for each month. These coefficients are estimated by least squares. The monthly runoff coefficients of the basin are calculated by

$$\sigma_t = \frac{Q_t}{P_t} \quad \ldots (2)$$

where $Q_t = \sum_{p=1}^{N} Q_{p,t}/N$ and $P_t = \sum_{p=1}^{N} P_{p,t}/N$, the mean monthly discharge and converted rainfall, respectively, both expressed in m^3/sec by multiplying rainfall values (mm) with the factor $A \times 10^3/(T \times 86400)$, where A = the area of the basin in km^2, and T = the duration of the month in days. The coefficients of the model are recognised so that the model may also be used at ungauged sites.

Data Used

The model is calibrated using the data from the Silent Valley catchment of Kunthipuzha sub-basin (Fig 1) of Bharathapuzha. The Silent Valley reserve forest is one of the core zones of the Nilgiri Biosphere Reserve with an area of 90 km^2 and altitude ranges from 60m to 2400m above MSL. The discharge measuring station is located at Sairandri and the drainage area upto this station is 73.6 km^2. Monthly discharge and mean areal precipitation data for the months of June to October for a period of 13 years (1970 - 82) were used for calibration. A further three years data sample (1990, 1991 and 1993) was used for verification purpose.

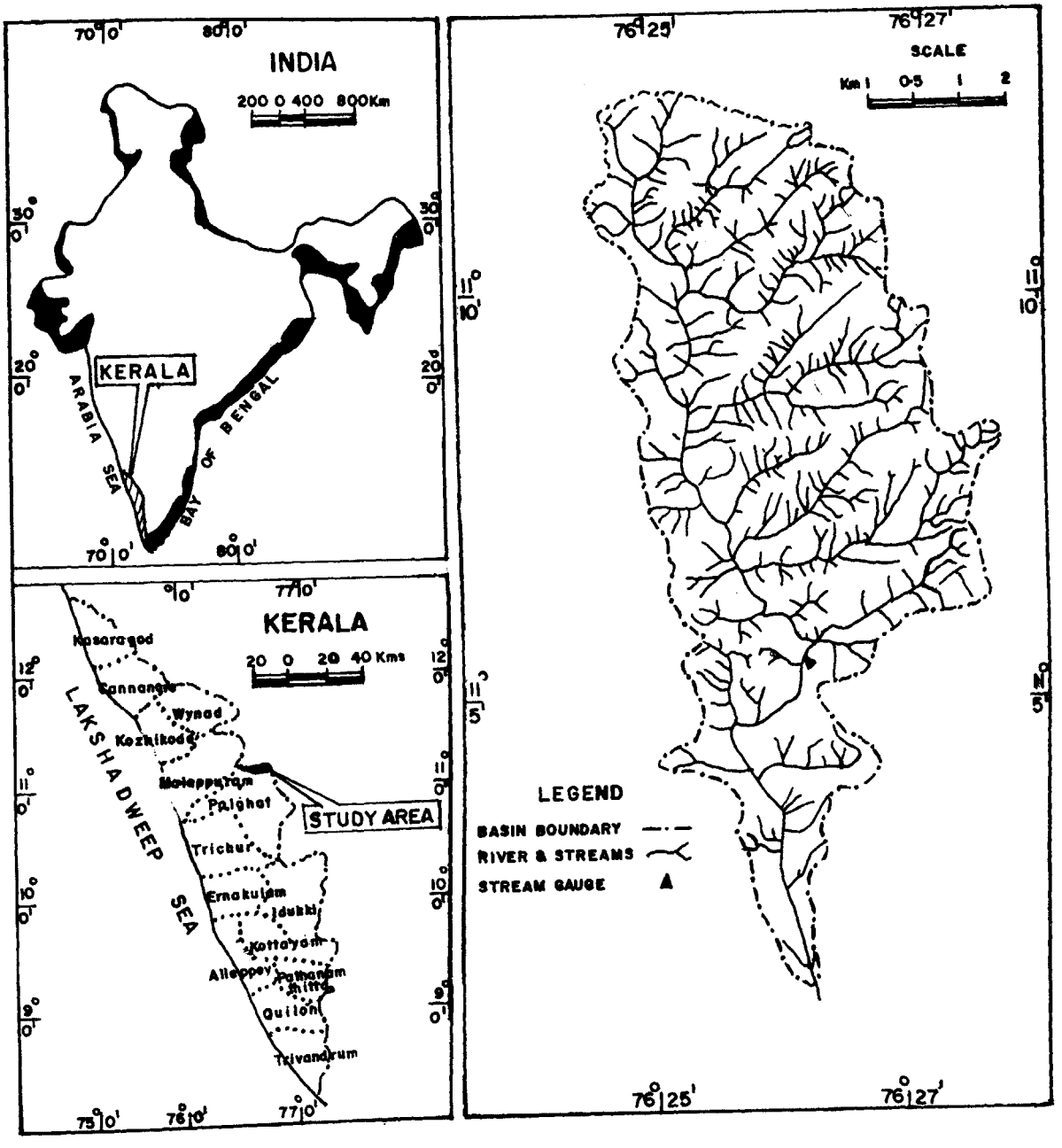


Fig 1 Location map of silent valley catchment of Kunthipuzha sub-basin

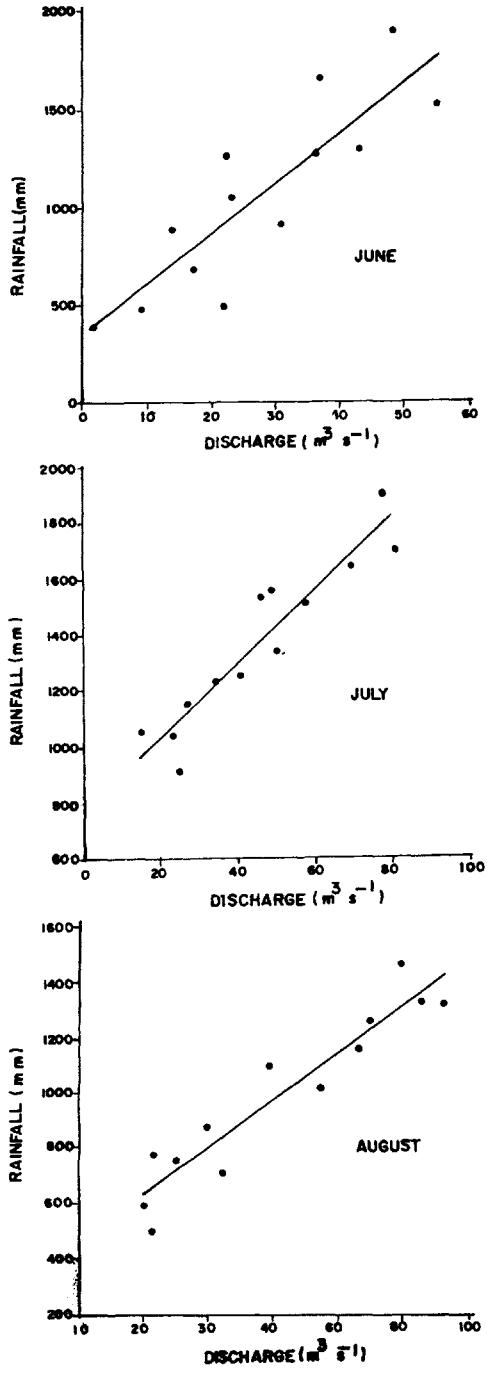


Fig 2 Monthly rainfall-runoff regression lines for Kunthipuzha sub basin for the months of June, July and August

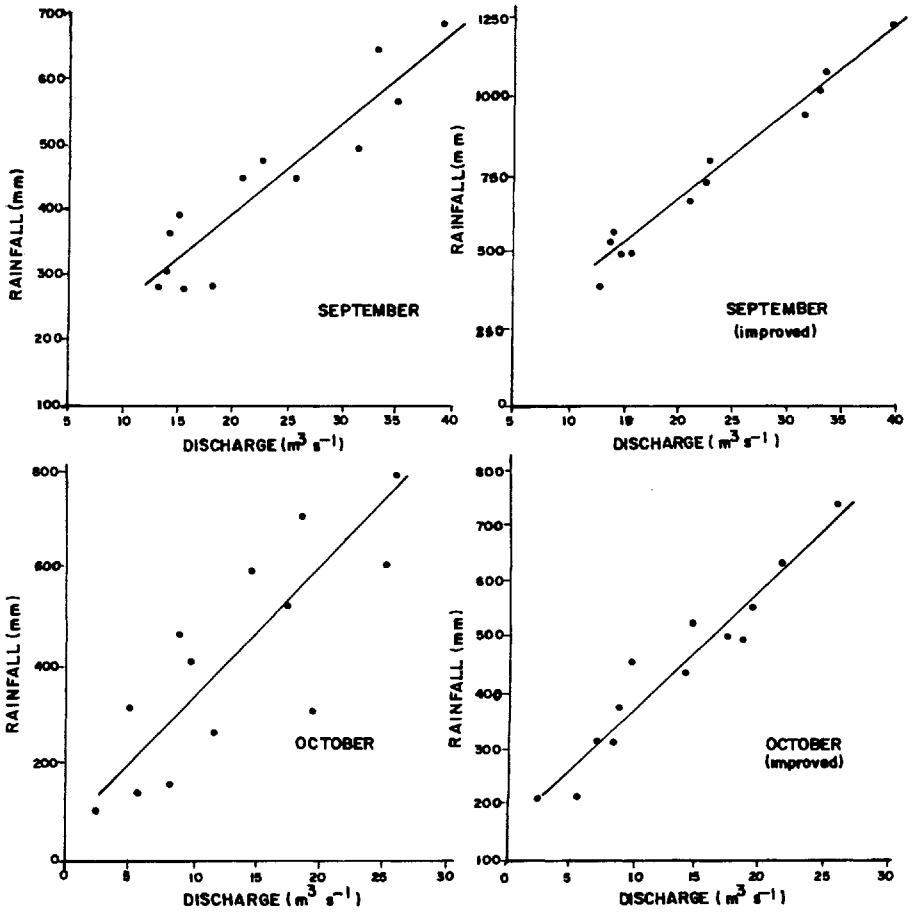


Fig 3 Monthly rainfall-runoff regression lines for Kunthipuzha sub basin for the months of September and October

Results and Discussions

We find that the rainfall-runoff correlations are not significant during the months of November to May. Using the memory parameter, an attempt has been made to search for any improvement in the correlation between rainfall and runoff during this period. Since there is no improvement even after using the memory parameter, the model is not applicable during the months from November to May. This is due to the fact that the rainfall is small during this period compared to the remaining months. In Silent Valley, 80% of the annual rainfall occurs during the southwest and the early part of northeast monsoon (June-October). Therefore, the model is only applicable to the period from June to October. The monthly rainfall and runoff are apparently linearly associated. The monthly rainfall-runoff regression from June to October are shown in Figs 2 & 3. It is found that the rainfall runoff correlation is maximum when $n = 0$ for the months June to August. After using the memory parameter, n=1, the correlation coefficient for September is improved from 0.92 (when n=0) to 0.95 and for October from 0.82 (when n=0) to 0.96. The improved correlation coefficients are given in Table I. The improved regression relation can be seen in Fig 3. The memory parameter n is 0 for the months from June to August and n is 1 for the months September and October. To estimate the model coefficients, the respective values of n for each month were substituted in eq. (1). The coefficients $a_{t,0}$ and $a_{t,1}$ of the model were estimated by least squares applied to eq. (1) and actual data. These parameters are given in Table I.

The coefficients $a_{t,0}$ and $a_{t,1}$ were plotted against the monthly runoff coefficients σ_t for the basin (Fig. 4b). The runoff coefficients for the basin divided by unit

Table I

Parameters of the rainfall-runoff model

Parameter	June	July	Aug	Sept	Oct
Historical discharge					
Mean (m^3/sec)	26.97	45.22	38.02	20.45	12.95
Standard deviation (m^3/sec)	13.25	19.05	16.34	7.86	6.59
Estimated discharge					
Mean (m^3/sec)	26.97	45.22	38.02	20.45	12.95
Standard deviation (m^3/sec)	15.57	20.41	17.35	8.27	6.89
Memory parameter n	0	0	0	1	1
Regression Coefficients					
$a_{t,0}$	−2.140	−45.950	−9.680	−1.870	−5.520
$a_{t,1}$	0.028	0.067	0.051	0.032	0.042
Correlation coefficient	0.85	0.93	0.94	0.95	0.96
Runoff coefficient (σt)	0.92	1.21	1.47	1.78	1.13

area of basin (km^2) were plotted against the corresponding monthly rainfall values (Fig.4a). Five different curves were drawn through these points depending on the month of the year. From Fig. 4a, one can obtain the runoff coefficient/ km^2 corresponding to the rainfall in mm for month t. Multiplying this value by the area of the basin, the coefficients $a_{t,0}$ and $a_{t,1}$ may be read off from Fig. 4b. The coefficient $a_{t,0}$ is -45.95 for July and it has to be retained irrespective of the value of runoff coefficient. Therefore, except for July $a_{t,0}$ can be obtained from Fig. 4b. This is due to very high rainfall in July compared to that in other months. Then from equation (1), the runoff at month t is estimated taking the parameter n=0 for June, July and August and n=1 for September and October. This procedure, which is applicable to ungauged sites of the region needs only the monthly rainfall values and the area of the basin as input.

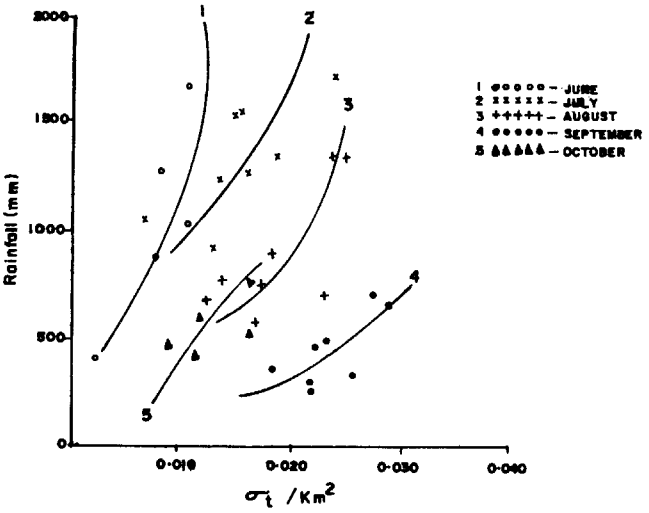
Applying the model in equation (1) to the data of calibration period the monthly discharges $Q_{p,t}$ are estimated by using the monthly rainfall of the basin and the coefficients. It is found that the model explains 91% of the total variance. A portion of the estimated flows and corresponding historical flows are given in Fig. 5. The results indicate that the estimates from the models are very good. The standard error (SE) of monthly flow estimates is given by the expression

$$SE = \left[\frac{1}{N \times m} \sum_{p=1}^{N} \sum_{t=1}^{m} \left[\frac{\hat{Q}_{p,t} - Q_{p,t}}{\hat{Q}_{p,t}} \right]^2 \right]^{1/2} \qquad \ldots(3)$$

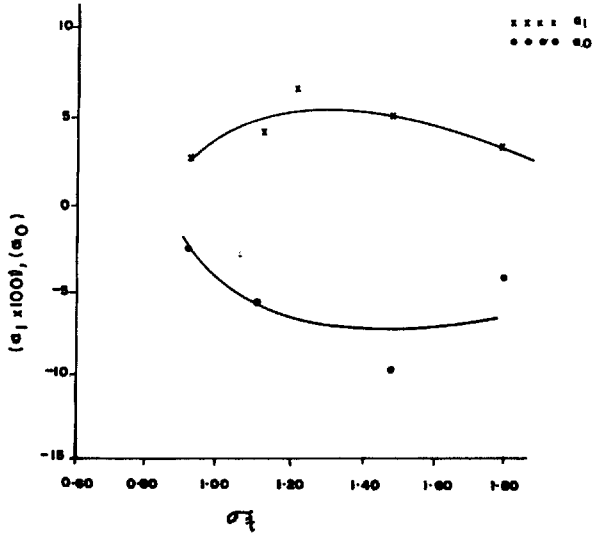
where $\hat{Q}_{p,t}$ and $Q_{p,t}$ are estimated and observed values respectively. The standard error of monthly flow estimates is found to be 0.2. The model also preserves the historical monthly means and standard deviations as given in Table I. The model is verified using the data of 3 years (1990, 1991 and 1993) (Fig 6). It is found that the model explains 89% of the total variance during the verification period with a standard error estimate 0.29.

Conclusions

The simple regional rainfall-runoff model presented here can be applied to estimate monthly runoff of basins in the region. The memory parameter n is equal to one for September and October and equal to zero for June, July and August. Good relationship exists between the coefficients of the model and the monthly runoff coefficients of the basin. The model explains 91% of the total variance. The model can be applied for : (1) the estimation of monthly runoff values at the measuring station, even after the operation of the station is terminated; (2) continuous estimation of monthly inflows to all operating stations, if any, of this region; (3) estimation of missing monthly flows and (4) forecasting monthly



4(a) Basin's runoff coefficients



4(b) Model coefficients

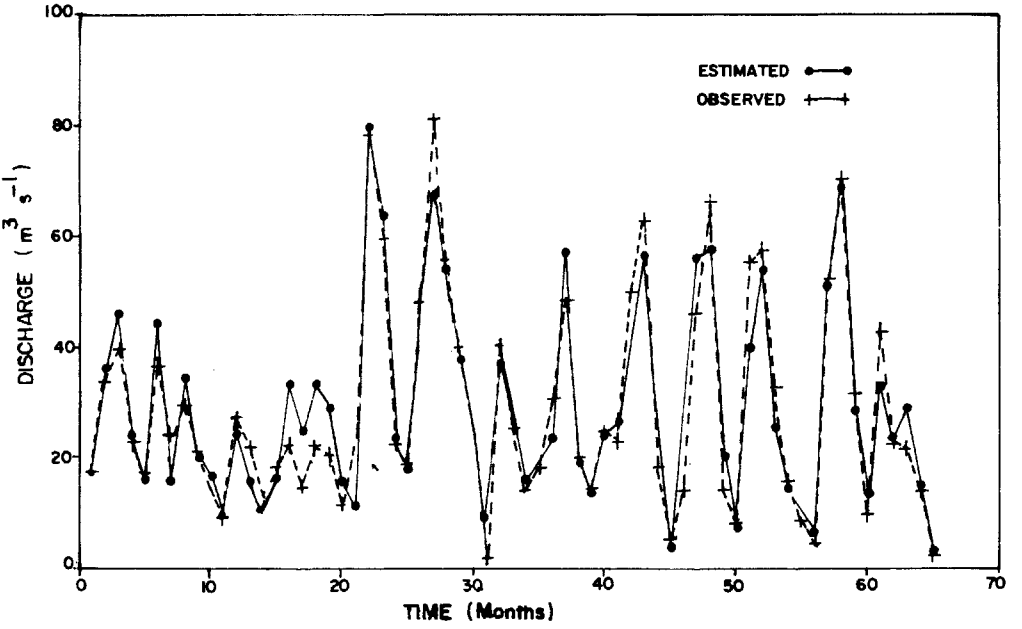


Fig 5 Application of the model (calibration period)-observed and estimated discharges for a period of 13 years (1970-82)

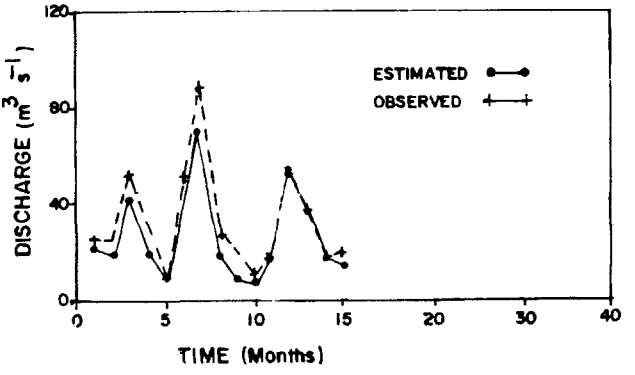


Fig 6 Verification of the model—both observed and estimated discharges for three years (1990, 91 and 93)

flows at various gauged or ungauged sites of the river. The model is not applicable during the months of November to May because of the poor correlation between rainfall and runoff even after using the memory parameter. This is not a serious concern, since 80% of the annual rainfall in Silent Valley is received during south-west monsoon period for which the model can be applied successfully.

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