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APPLICATION OF BIVARIATE THOMAS-FIERING MODEL FOR MONTHLY STREAMFLOW GENERATION IN MAHANADI RIVER BASIN

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ABSTRACT

Data generation procedure is used to provide equally likely flow sequences to the historical one in capacity yield analysis. The synthetic give the designer an idea of the probability of failure-storage relation in simulation studies.

The monthly flow models can be broadly classified in two categories namely (1) univariate and (ii) multivariate. Univariate models are used when synthetic sequences of flow are required at one particular site and the cross correlation with flows at other site are not required to be preserved. The use of univariate models to generate synthetic flows at a site is somewhat limited as the flows at various sites tend to be interdependent.

In the present study, the computer programme for Bivariate Thomas Fiering model has been developed based on the algorithm given by Clarke. This has been used for 11 years, 37 years and 100 years, simultaneous generation of monthly streamflows at (i) Hirakud and Salebhata, and (ii) Hirakud and Kantamal using 11 years concurrent period (1972-82) observed data. The model preserves monthly means standard deviations, correlation with previous month and cross-correlation structure between two sites. The monthly flows have been generated at Hirakud, Salebhata and Kantamal independently using univariate Thomas Fiering model also. The monthly means, standard deviations and correlation with previous month of observed and generated flows have been compared on the basis of sum of squares of error in mean, sum of squares of error in standard deviation and absolute error in correlation with previous month on annual (June-May) and monsoon (June-October) basis.

The results indicate good performance of the bivariate Thomas

Fiering model for the generation of monthly streamflows at two sites simultaneously. The model satisfactorily preserves monthly means, standard deviations, correlation with previous month and cross correlation structure between two sites.

1.0 INTRODUCTION

Basic hydrologic data is most important in all the water resources projects. Generally hydrologic data of sufficient long period is not available. Most of the existing flow records are very short, generally less than 25 years. The exact pattern of the flows during the historical/ observed period is extremely unlikely to recur during the economic life of the project. By generating several streamflow sequences with the same statistical characteristics as of the observed flows and all assumed to be equally likely to occur, the designer is able to decide the basis of expected behaviour of the system.

Data generation procedures are used to provide equally likely flow sequences to the historical one in capacity yield analysis. The synthetic sequences give the designer an idea of the probability of failure-storage relation in simulation studies.

Models used to generate synthetic sequences depend greatly on the time interval (yearly, monthly, daily or hourly) for which sequences of synthetic streamflows are required. Over the past decade a number of models have been developed to generate monthly flows for use in the design and operation of water resources systems. The monthly flow models can be broadly classified in two categories namely (i) univariate and (ii) multivariate.

Univariate models are used when synthetic sequences of flow etc. are required at one particular site and the cross correlation with flows at other sites are not required to be preserved. For this purpose, basically there are two type of approaches available: (i) Univariate Thomas Fiering approach and (ii) Disaggregation processes.

Some times, it is necessary to generate simultaneous sequences of several hydrological variables. In general water resources system planning is concerned with determining the size and operation of not one but several reservoirs. In such cases, the use of univariate model for generating synthetic flows at each site of interest is limited, because the flows at various sites tend to be interdependent. Hence, the multisite properties of the flows must be considered in generating synthetic flows at all the sites (Matalas, 1967).

For generating simultaneous flows at two sites bivariate models are required. Bivariate Thomas Fiering model is one such model.

The present study has been done using the 11 years (1972-82) runoff data at Hirakud, Salebhata and Kantamal sites of Mahanadi river basin, adopting the bivariate Thomas Fiering model algorithm given by Clarke(1973).

2.0 REVIEW

Hazen (1914) is considered to be the first to recognise the desirability of extending hydrologic data. Sudler (1927), Barnes (1954) and Hurst (1936-60) are some more to devote their efforts in generating synthetic annual flows. Later on more comprehensive models were developed such as that of Thomas and Fiering (1962). Fiering (1964) gives details of principal component analysis to eliminate bias in the serial correlation coefficient(of lag) among the synthesized data. He applies it for the simultaneous generation of synthetic flows at a key station and at a satellite station. Lawrance (1976) has given a modified version of the Fiering two station model. Matalas (1967) has presented an alternative to the multivariate Thomas Fiering model. This model requires very few parameters but at the same time introduces restrictive assumptions concerning the serial and cross correlation structure of the sequences. Srikanthan and Macmohan (1982) have presented a study for stochastic generation of monthly streamflows.

Clarke (1973) has presented method for generation of synthetic sequences of several hydrological variables e.g.the bivariate extension of the Thomas-Fiering model; the general multivariate extension of the Thomas Fiering model and the multivariate Matalas model.

3.0 STATEMENT OF THE PROBLEM

The main objectives of the study is to develop and implement a computer programme to generate monthly streamflow sequences at (i) Hirakud, (ii) Salebhata and (iii) Kantamal. For this purpose the programme for bivariate Thomas Fiering model has been developed based on algorithm given by Clarke (1973). The model simultaneously generates synthetic data at two sites and preserves serial and cross correlation structure alongwith mean and standard deviation of monthly flow. The performance of the model has been judged by the comparison of the statistical parameters of historical flows and the generated flows. The 100 year series of monthly flows at each site has been generated using univariate Thomas Fiering model, with 11 years observed flows, and the results have been compared with corresponding generated series using Bivariate model. Seth, Goel and Bhatia (1984) give details of univariate Thomas Fiering model.

4.0 DESCRIPTION OF STUDY AREA

The Mahanadi basin lies between North latitudes 19°21' and 23°35' and east longitudes 80°30' and 84°50'(Fig.1). The basin extends over an area of 141592 sq.km. It is nearly 4.3% of the geographical area of the country. Lying in the north-east of the Deecan Plateau, the basin covers large areas in the states of Madhya Pradesh and Orissa and only small areas in Bihar and Maharashtra. The state wise distribution of the drainage basin of the river is given below:

State	Drainage Area(Sq.km)
Bihar	635
Madhya Pradesh	75,138
Orissa	65,581
Maharashtra	238
Total	141,592

The Mahanadi basin is bounded on the north by the Central India hills, on the south and east by the Eastern Ghats and on the west by the Maikala range. The upper basin is a saucer-shaped depression known as the Chattigarh. The basin is circular in shape with a diameter of about 400 km and an exist passage of about 160 km length and 60 km breadth.

There are four well defined physical regions in the basin namely (i) The northern plateau, (ii) The Eastern Ghats,(iii) the Coastal Plain; and (iv) the erosional plains of the central table land. The Northern Plateau and the Eastern Ghats are well forested hilly regions. The coastal plains stretching over the districts of Cuttack and Puri covers the large delta formed by the Mahanadi and is fertile area well suited for intensive cultivation. The errosional plains of the central table land are traversed by the Mahanadi and its tributaries.

SUB CATCH MENT NO.	NAME OF CATCHMENT	CATCHMENT AREA IN SQ KM
①	UPSTREAM OF HIRAKUD	83400
②	ONG UPTO SALEBHATA	4650
③	TEL UPTO KANTAMAL	19600
④	REMAINING CATCHMENT BETWEEN HIRAKUD AND TIKARPARA	16350
⑤	INTERMEDIATE CATCHMENT BETWEEN TIKARPARA AND NARAJ	7700

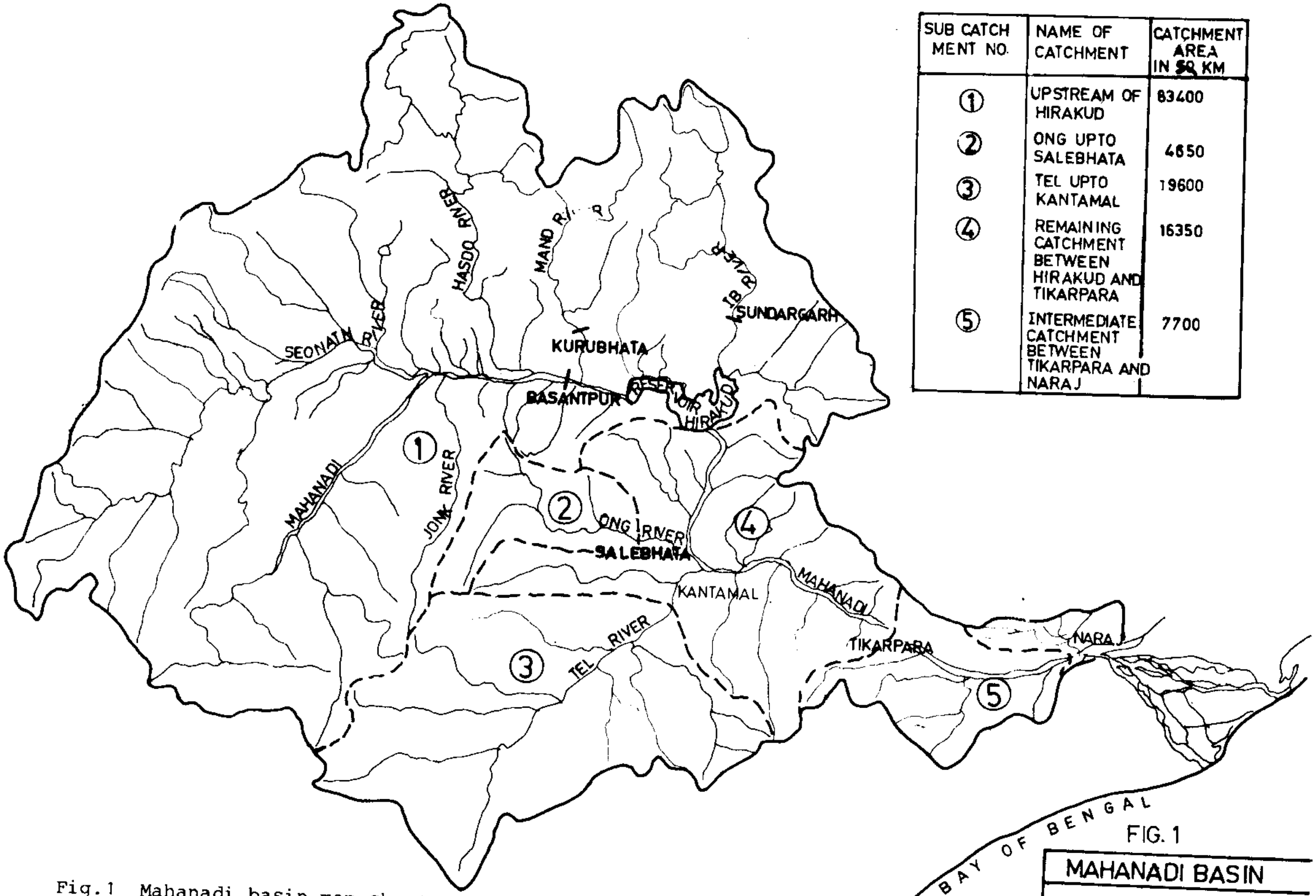


Fig.1 Mahanadi basin map showing Mahanadi river's main tributaries & gauge & discharge sites

5.0 AVAIABILITY OF DATA

In Mahanadi river basin the availability of flow data for various sites is as follows:-

Site	River	Period	Catchment area in sq.km.
(i) Hirakud	Mahanadi	1946-1982	3400
(ii) Salebhata	Ong	1972-1982	4650
(iii) Kantamal	Tel	1972-1982	19600
(iv) Tikerpara	Mahanadi	1972-1982	124000
(v) Naraj	Mahanadi	1946-1982	131700

The gaps in the flow data have been filled up earlier. (NIH, 1986) In this study, the flows at Hirakud, Salebhata and Kantamal for the period 1972-1982 only have been considered. The monthly flows for three sites are given in Tables 1,2,&3 respectively.

TABLE 1: MONTHLY FLOWS IN mm FOR HIRAKUD FROM 1972-82

YEAR	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1972	1.8	63.6	107.5	82.0	21.1	10.4	6.6	2.3	2.1	1.2	1.0	0.4
1973	1.4	125.2	179.0	190.4	112.6	30.3	6.8	3.8	2.3	0.8	0.3	0.4
1974	3.2	42.6	125.6	14.8	17.6	5.4	3.6	1.5	1.2	0.9	0.4	0.4
1975	5.6	101.5	220.2	98.9	57.9	15.3	5.7	3.2	2.2	1.2	0.6	0.4
1976	1.8	79.4	191.9	92.9	9.9	4.5	2.5	1.3	0.8	0.7	0.3	0.4
1977	23.8	115.9	170.2	110.9	28.1	9.0	5.1	2.2	2.6	2.3	0.4	0.4
1978	13.1	82.0	222.7	84.1	18.5	8.8	6.0	2.8	2.9	0.7	0.3	0.4
1979	2.5	34.0	92.3	9.8	14.4	4.0	2.9	1.1	0.8	0.7	0.3	0.4
1980	33.4	143.9	121.4	217.8	19.7	7.4	3.7	2.5	1.2	0.7	0.7	0.4
1981	4.3	62.8	133.0	76.0	27.4	7.3	4.0	2.9	3.1	3.2	0.3	0.4
1982	3.7	30.5	170.4	56.2	18.8	7.8	3.8	1.8	2.5	1.0	0.3	0.5

Table 2: Monthly flows in mm for Salebhata from 1972-82

YEAR	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1972	0.6	96.9	93.6	56.8	30.2	11.6	2.7	1.3	2.2	1.0	0.6	0.1
1973	0.3	314.0	193.1	93.9	84.4	19.8	2.3	1.6	1.4	0.6	0.4	0.1
1974	2.8	12.9	186.0	7.5	5.7	1.8	0.4	0.5	0.7	0.6	0.4	0.0
1975	1.3	53.2	115.5	67.7	19.8	5.8	0.9	0.5	1.0	0.4	0.5	0.4
1976	0.3	116.3	220.5	140.5	5.0	2.1	0.5	0.9	0.8	0.8	0.7	0.1
1977	2.6	36.8	136.3	132.2	9.4	4.5	1.7	1.1	1.5	1.6	0.5	0.2
1978	4.1	122.1	262.9	37.0	7.9	3.5	1.9	1.5	1.9	0.7	0.5	0.1
1979	1.1	9.5	73.3	5.8	6.6	1.5	0.3	0.6	0.5	0.7	0.4	0.0
1980	12.6	236.5	88.0	262.7	8.5	3.3	1.0	2.0	1.6	2.2	0.9	0.6
1981	0.7	13.1	200.9	94.0	19.4	7.3	1.7	1.4	1.3	2.7	1.0	0.1
1982	0.2	12.7	475.5	42.4	4.1	1.6	0.8	0.8	2.0	0.7	1.0	0.1

Table 3: Monthly flows in mm for Kantamal from 1972-82

YEAR	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY
1972	1.3	114.9	78.6	161.6	17.1	9.1	7.2	2.4	0.9	0.5	0.1	0.0
1973	2.4	261.5	131.6	90.5	61.4	37.2	7.2	2.6	1.1	0.4	0.1	0.1
1974	7.7	14.5	43.1	16.2	11.4	3.1	2.2	0.4	0.3	0.1	0.0	0.0
1975	9.3	67.4	136.1	79.4	29.9	17.2	6.4	1.5	0.6	0.1	0.0	0.2
1976	0.8	126.5	288.6	135.6	9.7	5.5	3.2	1.1	0.4	0.1	0.1	1.8
1977	2.8	74.1	177.2	257.2	15.7	12.6	5.9	2.3	1.5	0.9	0.4	0.2
1978	2.9	103.5	495.4	101.8	22.8	18.4	6.1	2.3	1.3	0.4	0.1	0.0
1979	36.3	77.2	141.0	14.7	28.5	4.0	2.2	1.2	0.3	0.1	0.1	0.0
1980	36.6	245.8	89.9	280.6	16.9	7.9	4.5	3.2	1.3	1.4	0.6	0.4
1981	1.3	6.5	208.2	94.0	27.1	8.9	4.4	1.5	0.7	1.4	0.4	0.3
1982	5.2	39.1	160.7	70.7	6.5	4.7	2.3	0.9	1.1	0.4	0.8	0.4

6.0 METHODOLOGY

Clarke (1973) has formulated the following algorithm for bivariate extension of Thomas Fiering model to generate flow sequences at two stations simultaneously. Various steps are described below:

1. Compute the monthly means and standard deviations for station 1. Let these be

$\bar{Y}_j^{(1)}$, $\bar{Y}_F^{(1)}$, $\bar{Y}_M^{(1)}$, ... $\bar{Y}_D^{(1)}$

and $S_j^{(1)}$, $S_F^{(1)}$, $S_M^{(1)}$ ..... $S_D^{(1)}$

2. Compute monthly means and standard deviations for stations 2. Let these be

$\bar{Y}_J^{(2)}$, $\bar{Y}_F^{(2)}$, $\bar{Y}_M^{(2)}$, ... $\bar{Y}_D^{(2)}$

$S_j^{(2)}$, $S_F^{(2)}$, $S_M^{(2)}$, $S_D^{(2)}$

3. Standardize the flows at each station by subtracting appropriate monthly means and by dividing by appropriate standard deviation. The standardized variables $Y_1^{(1)}$, $Y_1^{(2)}$, $Y_2^{(1)}$, and $Y_2^{(2)}$ etc. are calculated as follows

$$Y_1^{(1)} = (Y_J^{(1)} - \bar{Y}_J^{(1)}) / S_J^{(1)}$$

$$Y_1^{(2)} = (Y_J^{(1)} - \bar{Y}_J^{(2)} / S_J^{(2)}$$

$$Y_2^{(1)} = (F_F^{(1)} - \bar{Y}_F^{(1)})/S_F^{(1)}$$

$$Y_2^{(2)} = (Y_F^{(2)} - \bar{Y}_F^{(2)}) / S_F^{(2)}$$

and so on.

4. The Thomas Fiering model is then of the form

$$Y_t^{(1)} = b_{11}Y_{t-1}^{(1)} + b_{12}\, Y_{t-1}^{(2)} + \xi_t^{(1)} \qquad \ldots(1)$$

$$Y_t^{(2)} = b_{21}Y_{t-1}^{(1)} + b_{22}\, Y_{t-1}^{(2)} + \xi_t^{(2)} \qquad \ldots(2)$$

or in matrix form,

$$\begin{vmatrix} Y_t^{(1)} \\ Y_t^{(2)} \end{vmatrix} \begin{vmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{vmatrix} \begin{vmatrix} Y_{t-1}^{(1)} \\ Y_{t-1}^{(2)} \end{vmatrix} + \begin{vmatrix} t^{(1)} \\ t^{(2)} \end{vmatrix} \qquad \ldots(3)$$

Equations (1) and (2) refer to the streamflow from the two stations for the months January and February, a similar pair of equations holds for the months February and March,.... and so on. For each pair of months a total of seven parameters must be estimated for the model (3): b_{11}, b_{12}, b_{21}, b_{22}, var $\xi_t^{(1)}$, Var $\xi_t^{(2)}$ and cov ($\xi_t^{(1)}$; $\xi_t^{(2)}$). In addition to the 12 x 7 = 84 parameters required for a year, a further 48 parameters must also be estimated, bringing the total of 132 parameters.

The method of estimating these parameters is as follows:

(i) Abstract, from the complete record, the data for January and February and arrange in a table as follows (It is assumed that N years of data are available):

	February		January	
	Stream 1	Stream 2	Stream 1	Stream 2
Year 1:	$Y_2^{(1)}$	$Y_2^{(2)}$	$Y_1^{(1)}$	$Y_1^{(2)}$
Year 2:	$Y_{14}^{(1)}$	$Y_{14}^{(2)}$	$Y_{13}^{(1)}$	$Y_{13}^{(2)}$
Year 3:	$Y_{26}^{(1)}$	$Y_{26}^{(2)}$	$Y_{25}^{(1)}$	$Y_{25}^{(2)}$

(ii) Calculate the quantities

$$\Sigma_{11}(1,1) = ((y_1^{(1)} \times y_1^{(1)} + y_{13}^{(1)} \times y_{13}^{(1)}) + \ldots)/N$$

$$\Sigma_{11}(2,2) = ((y_1^{(2)} \times y_1^{(2)}) + (y_{13}^{(2)} \times y_{13}^{(2)}) + \ldots)/N$$

$$\Sigma_{11}(1;2) = ((y_1^{(1)} \times y_1^{(2)}) + (y_{13}^{(1)} \times y_{13}^{(2)}) + \ldots)/N$$

$$\Sigma_{11}(2,1) = \Sigma_{11}(1,2),$$

and arrange them in a table (matrix) as follows:

$$\Sigma_{11} = \begin{bmatrix} \Sigma_{11}(1,1) & \Sigma_{11}(1,2) \\ \Sigma_{11}(2,1) & \Sigma_{11}(2,2) \end{bmatrix}$$

(iii) Calculate the quantities

$$\Sigma_{22}(1,1) = ((y_2^{(1)} \times y_2^{(1)}) + (y_{14}^{(1)} \times y_{14}^{(1)} + \ldots)/N;$$

$$\Sigma_{22}(2,2) = ((y_2^{(2)} \times y_2^{(2)}) + (y_{14}^{(2)} \times y_{14}^{(2)}) + \ldots)/N;$$

$$\Sigma_{22}(1,2) = ((y_2^{(1)} \times y_2^{(2)} + (y_{14}^{(1)} \times y_{14}^{(2)}) + \ldots)/N;$$

$\Sigma_{22}(2,1) = \Sigma_{22}(1,2)$, and arrange them as a matrix:

$$\Sigma_{22} = \begin{bmatrix} \Sigma_{22}(1,1) & \Sigma_{22}(1,2) \\ \Sigma_{22}(2,1) & \Sigma_{22}(2,2) \end{bmatrix}$$

(iv) Compute the quantities:

$$\Sigma_{21}(1,1) = ((y_2^{(1)} \times y_1^{(1)} + (y_{14}^{(1)} \times y_{13}^{(1)}) + \ldots)/N;$$

$$\Sigma_{21}(1,2) = ((y_2^{(1)} \times y^{(2)}) + (y_{14}^{(1)} \times y_{13}^{(2)}) + \ldots)/N;$$

$$\Sigma_{21}(2,1) = ((y_2^{(2)} \times y_1^{(1)}) + ({}_{14}^{(2)} \times y_{13}^{(1)}) + \ldots)/N;$$

$$\Sigma_{21}(2,2) = ((y_2^{(2)} \times {}_1^{(2)}) + (y_{14}^{(2)} \times y_{13}^{(2)}) + \ldots)/N;$$

and arrange them as a matrix

$$\Sigma_{21} = \begin{bmatrix} \Sigma_{21}(1,1) & \Sigma_{21}(1,2) \\ \Sigma_{21}(2,1) & \Sigma_{21}(2,2) \end{bmatrix}$$

(v) The estimates of b_{11}, b_{12}, b_{21}, b_{22} are given by the following matrix equation

$$\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} \Sigma_{21}(1,1) & \Sigma_{21}(1,2) \\ \Sigma_{21}(2,1) & \Sigma_{21}(2,2) \end{bmatrix} \begin{bmatrix} \Sigma_{11}(2,2) & \Sigma_{11}(1,2) \\ \Sigma_{11}(2,1) & \Sigma_{11}(1,1) \end{bmatrix}$$

where

$\Delta \quad \Sigma_{11}(1,1)\ \Sigma_{11}(2,2) - \Sigma_{11}(2,1)\ \Sigma_{11}(1,2)$, in explicit terms,

$$b_{11} = (\ \Sigma_{21}(1,1)\ \Sigma_{11}(2,2) - \Sigma_{21}(1,2)\ \Sigma_{21}(1,2)\ \Sigma_{11}\ (2,1))/\Delta \quad ...(4)$$

$$b_{12} = (\Sigma_{11}(1,1)\ \Sigma_{21}(1,2) - \Sigma_{21}(1,1),\ \Sigma_{11}(1,2))/\Delta \quad ...(5)$$

$$b_{21} = (\Sigma_{21}(2,1)\ \Sigma_{11}(2,2) - \Sigma_{21}(2,2)\ \Sigma_{11}(2,1))/\Delta \quad ...(6)$$

$$b_{22} = (\Sigma_{11}\ (1,1)\ \Sigma_{21}(2,2) - \Sigma_{21}(2,1)\ \Sigma_{11}(1,2))/\Delta \quad ...(7)$$

(vi) The variances var $\xi_t(2)$, and covariance cov ($\xi_t(1)$, $\xi_t(2)$) given by

$$\mathrm{Var}\,\xi_t^{(1)} = \Sigma_{22}(1,1) - b_{11}\ \Sigma_{21}(1,1) - b_{12}\ \Sigma_{21}(1,2) \quad ...(8)$$

$$\mathrm{Var}\,\xi_t^{(2)} = \Sigma_{22}(2,2) - b_{11}\ \Sigma_{21}(2,1) - b_{22}\ \Sigma_{21}(2,2) \quad ...(9)$$

$$\mathrm{Cov}\ (\xi_t^{(1)}, \xi_t^{(2)}) = \Sigma_{22}(1,2) - b_{11}\ \Sigma_{21}(2,1) - b_{12}\ \Sigma_{21}(2,2) \quad ...(10)$$

(vii) The whole of the above procedure, from steps (i) to (vi), is repeated for the months February and March, the months March and April and so on.

(viii) To generate a synthetic sequence we start by choosing values to initiate the sequence, commonly the Means $\bar{y}_j^{(1)}$, $\bar{y}_j^{(2)}$, so that $y_1^{(1)} = 0$, $y_1^{(2)} = 0$- Now it is required to generate the values

$\xi_2^{(1)*}$ and $\xi_2^{(2)*}$

with a bivariate normal distribution determined by (8), (9) and (10). To do this first generate by the Box-Muller method, pseudo-random Normal deviates u_1, u_2. These are transformed to give

$$\xi_2^{(1)*} = u_1 \sqrt{\text{var} \; \xi_t^{(1)}}$$

$$\xi_2^{(2)*} = u_1 (\text{Cov} (\xi_t^{(1)} , \xi_t^{(2)}) / \text{var} \; \xi_t^{(1)}) +$$

$$u_2 \sqrt{(\text{var} \; \xi_t^{(2)} - \text{cov}^2 (\xi_t^{(1)} \; \xi_t^{(2)}) / \text{var} \; \xi_t^{(1)})}$$

The generated sequence then begins

$$y_2^{(1)} = (b_{11} x 0) + (b_{12} \times 0) + \xi_2^{(1)*}$$

$$y_2^{(2)} = (b_{21} \; x 0) + (b_{22} \; x 0) = \xi_2^{(2)*}$$ and so on

Finally, the $y_t^{(1)}$ and $y_t^{(2)}$ are retransformed by such calculations as

$$y_J^{*(1)} = y_1^{(1)} \quad s_J^{(1)} + \bar{y}_J^{(1)}$$

$$y_j^{*(2)} = y_1^{(2)} \quad s_J^{(2)} + \bar{y}_J^{(2)}$$

7.0 ANALYSIS

Monthly streamflows have been generated at the following sites using Bivariate Thomas Fiering mode.

1.(a) Hirakud with reference to Salebhata

(b) Salebhata with reference to Hirakud

2.(a) Hirakud with reference to Kantamel

(b) Kantamal with reference to Hirakud

The length of the generated streamflows is

(a) 11 years, (b) 37 years, and (c) 100 years

The length of generated data as 11 years and 37 years has been chosen as the length of observed data is 11 years and 37 years is the length of long term streamflows available at Hirakud. Length of generated data as 100 years has been chosen arbitrarily.

Observed streamflows data for the period 1972-82 (11 years) only have been used.

The following statistical parameters of observed data and generated data have been computed and compared

(a) Mean of monthly flows

(b) standard deviation of monthly flows

(c) correlation with previous month

(d) cross correlation with another site

The equations used for the computation of above statistical parameters are

$$\bar{X}_j = \frac{\sum_{i=1}^{N} X_{i,j}}{N}$$

$$S_j = \left(\sum_{i=1}^{N} (x_{i,j} - X_j) \right)^{1/2}$$

$$r_j = \frac{\sum_{i=1}^{N} (X_{i}, \quad - \bar{X}_{j+1}) (X_{ij} - \bar{X}_j)}{\sum_{i=1}^{N} (X_{i,j} - \bar{X}_j)^2)^{1/2} (\sum_{i=1}^{N} (X_{i,j} - X_{j+1})^2)^{1/2}}$$

$$r_o = (\sum_{i=1}^{N} (X_{i,j} - \bar{X}_j))^{1/2} (\sum_{i=1}^{N} (Y_{i,j} - \bar{Y}_j))^{1/2}$$

where,

$X_{i,j}$ = monthly flow for j^{th} month in i^{th} year for site X

$\bar{X}_j$ = mean flow of jth month for site X

S_j = standard deviation of jth month flows for site X

$X_{i+1,j+1}$ = monthly flow for $(j+1)^{th}$ months in $(i+1)^{th}$ year for site X

$Y_{i+1,j+1}$ = monthly flow for (j+1) th month in $(i+1)^{th}$ year for site X.

$Y_{i,j}$ = monthly flow for j^{th} month in ith year for site Y.

r_j = Correlation of $(j+1)^{th}$ month flows with jth month flows.

r_o = cross correlation for the j^{th} month flows between X and Y sites.

The monthly flows (100 years) at all the three sites have been generated by univariate Thomas Fiering model. The results of bivariate Thomas Fiering model have been compared with the results of univariate Thomas Fiering model on the basis of following criteria on annual (June-May) basis and on monsoon basis(June-Oct).

(i) Sum of squares of error in mean

(ii) sum of squares of error in standard deviation

(iii) Absolute error in correlation with previous month sum of squares of error in mean (R_m) is given by

$$R_m = \sum_{j=1}^{n} (M_{Q,j} - M_{g,j})$$

where,

R_m sum of squares of error in mean

$M_{q,j}$ mean of jth months flows (observed)

n Number of months

$M_{g,j}$ mean of jth months flows (generated)

Similarly sum of squares of error in standard deviation (R s) is given by

$$R\ s = \sum_{j=1}^{n} (S_{o,j} - S_{g,j})^2$$

where,

R s Sum of squares of error in standard deviation

So,j standard deviation of jth month's flows (observed)

$S_{g,j}$ Standard deviation of jth months flows (generated)

The values of n are 12 and 5 in case of annual and monsoon respectively.

Absolute error in correlation with previous month ERI is given by

$$ERI = \sum_{j=1}^{n} (r_{o,j} - r_{g,j})$$

where,

ERI is absolute error in correlation with previous month.

$r_{o,j}$ correlation with previous month in observed data for jth month.

$r_{g,j}$ Correlation with previous month in generated data for jth month.

The listing of the source file (Bivariate Thomas Fiering model) has been given in Appendix I. Data file (to generate flows at Hirakud and Kantamal simultaneously) and output file are in Appendix II and III respectively.

8.0 RESULTS

As stated earlier monthly streamflows of (i) 11 years, (ii) 37 years, (iii) 100 years length have been generated at the following sites using bivariate Thomas Fiering model.

1.(a) Hirakud with reference to Salebhata

(b) Salebhata with reference to Hirakud

2.(a) Hirakud with reference to Kantamal

(b) Kantamal with reference to Hirakud

The monthly flows for 100 years at Hirakud, Salebhata & Kantamal have also been generated using uni-variate Thomas Fiering model for the sake of comparison. The performance of the model has been compared on the basis of reproduction of statistical parameters (mean, standard deviation, correlation with previous month (r_1) and cross correlation with the second site (r_o)) for different lengths of generated flows. The sum of squares of difference in mean of observed and generated flows R_m, sum of squares of difference in standard deviation of observed and generated flows, R_s and absolute error in co-relation with previous month ER_1, represented by absolute difference of the corresponding values of r_1, for all the 12 months (as well as for monsoon months (June - October), have also been computed to judge the overall performance of the model. The results for the above-mentioned four cases are being discussed as follows:-

8.1 Monthly Streamflow Generation for Hirakud and Salebhata

8.1.1 Hirakud with reference to Salebhata

The statistical parameters (mean, standard deviation, correlation with previous month and cross co-relation with corresponding flows for Salebhata) of observed (1972-82) and generated monthly flows (i) 11 years, (ii) 37 years and (iii) 100 years) are given in table 4 and also plotted in Figs.2,3,4&5. It is seen that for 11 years length of generated data, the 4 parameters(mean, standard deviation r_o and r_1) do not match well. However, for 37 years and 100 years length of generated data there is a good reproduction of means though standard deviation, r_o and r_1 still do not match completely. The overall performance of the model is quite good when the generated sample is of 100 years length as clearly indicated by Figs.2,3,4&5.

The comparison of performance of bivariate model for Hirakud site using data of Salebhata and of univariate model for Hirakud site has been indicated by the values of sum of squares of error in reproduction of mean and standard deviation of annual basis and on monsoon season basis in table 8. It is seen that as the length of generated sample increases for the bivariate model the reproduction of mean and standard deviation both on annual basis as well as monsoon basis is improved. However, the corresponding sum of squares error for univariate model are relatively better. It seems to be due to somewhat poor correlation between two sites for flows during August. Absolute error in reproduction of correlation with previous months in case of bivariate Thomas Fiering model (100 years) and univariate Thomas Fiering model (100 years) are 0.672 and 0.504 respectively on annual basis and 0.382 and 0.278 on monsoon basis. This indicates that preservation of correlation with previous month is better in case of univariate Thomas Fiering model.

8.1.2 Salebhata with reference to Hirakud

The statistical parameters(mean, standard deviation, correlation with previous month and cross correlation with

TABLE 4 : STATISTICAL PARAMETERS OF OBSERVED AND GENERATED HIRAKUD FLOWS WITH REFERNCE TO SALEBHATA

SN. MONTH	Original 11 years				Generated 11 years				Generated 37 years				Generated 100 years			
	Mean	SD	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o
JUNE	8.6	10.6	-0.065	0.869	9.0	8.9	0.046	0.962	8.6	6.9	-0.142	0.725	9.7	6.5	-0.030	0.731
JULY	80.1	38.0	0.661	0.743	92.8	33.7	0.562	0.595	80.1	33.6	0.475	0.672	83.0	31.2	0.517	0.686
AUG	157.7	44.5	0.318	0.398	179.4	50.1	0.649	0.381	157.4	36.8	0.418	0.244	157.4	40.3	0.398	0.410
SEPT	94.0	63.5	0.213	0.823	88.6	52.7	0.422	0.919	79.5	51.1	0.112	0.923	82.6	57.3	0.161	0.860
OCT	31.5	29.7	0.520	0.920	33.3	26.3	0.029	0.953	29.4	22.6	0.310	0.916	30.5	23.4	0.591	0.894
NOV	10.2	7.4	0.982	0.876	10.5	7.5	0.983	0.943	9.5	6.0	0.971	0.832	9.7	6.3	0.972	0.841
DEC	4.6	1.5	0.735	0.853	4.6	1.2	0.645	0.806	4.9	1.1	0.455	0.735	4.6	1.4	0.622	0.847
JAN	2.3	0.8	0.772	0.529	2.7	0.7	0.616	0.412	2.5	0.6	0.597	0.281	2.4	0.7	0.802	0.419
FEB	2.0	0.8	0.552	0.622	2.3	0.9	0.703	0.671	2.0	0.7	0.522	0.530	2.0	0.8	0.628	0.648
MAR	1.2	0.8	0.602	0.694	1.7	0.9	0.607	0.899	1.3	0.7	0.540	0.812	1.3	0.7	0.591	0.742
APR	0.4	0.2	-0.081	0.030	0.4	0.2	0.063	0.008	0.4	0.2	-0.020	0.131	0.5	0.2	-0.138	0.026
MAY	0.4	0.0	-0.21	-0.117	0.4	0.0	0.025	0.062	0.4	0.0	-0.233	0.092	0.4	0.0	-0.255	0.126

r_1 correlation with previous month

r_o cross correlation between Hirakud and Salebhata

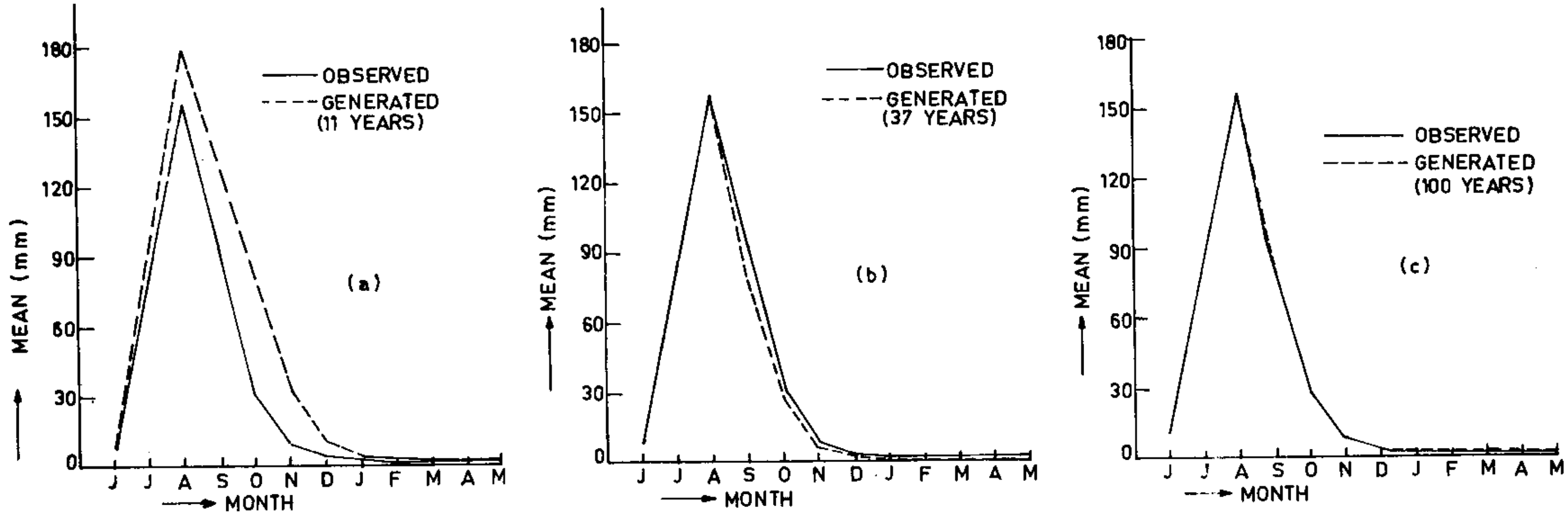


Fig.2 Comparison of monthly means of observed & generated Hirakud flows with reference to Salebhata

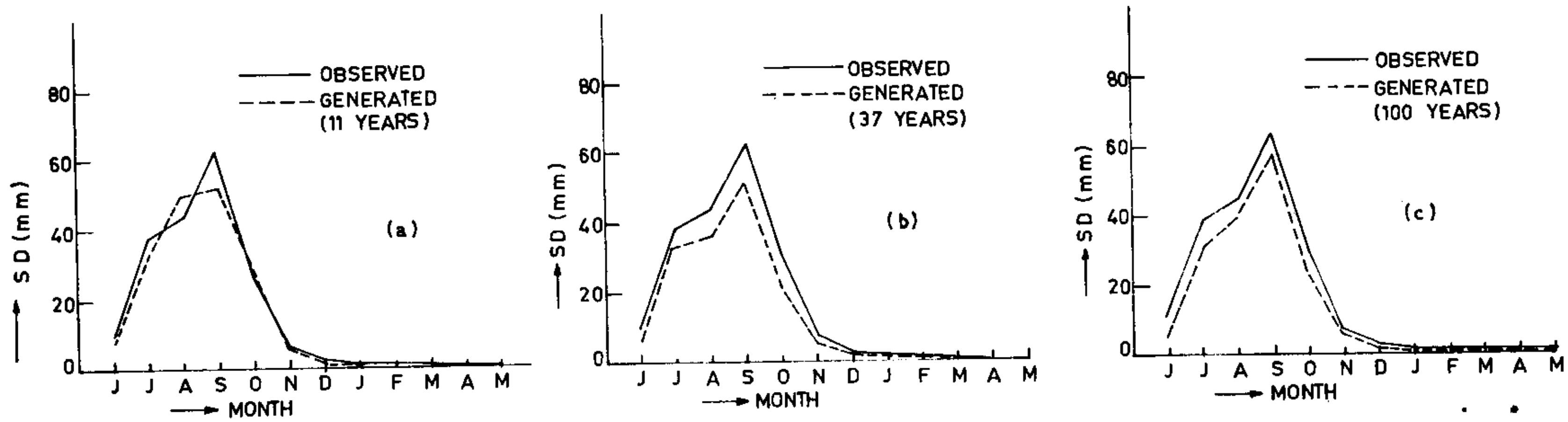


Fig.3 Comparison of monthly standard deviations of observed and generated Hirakud flows with reference to Salebhata.

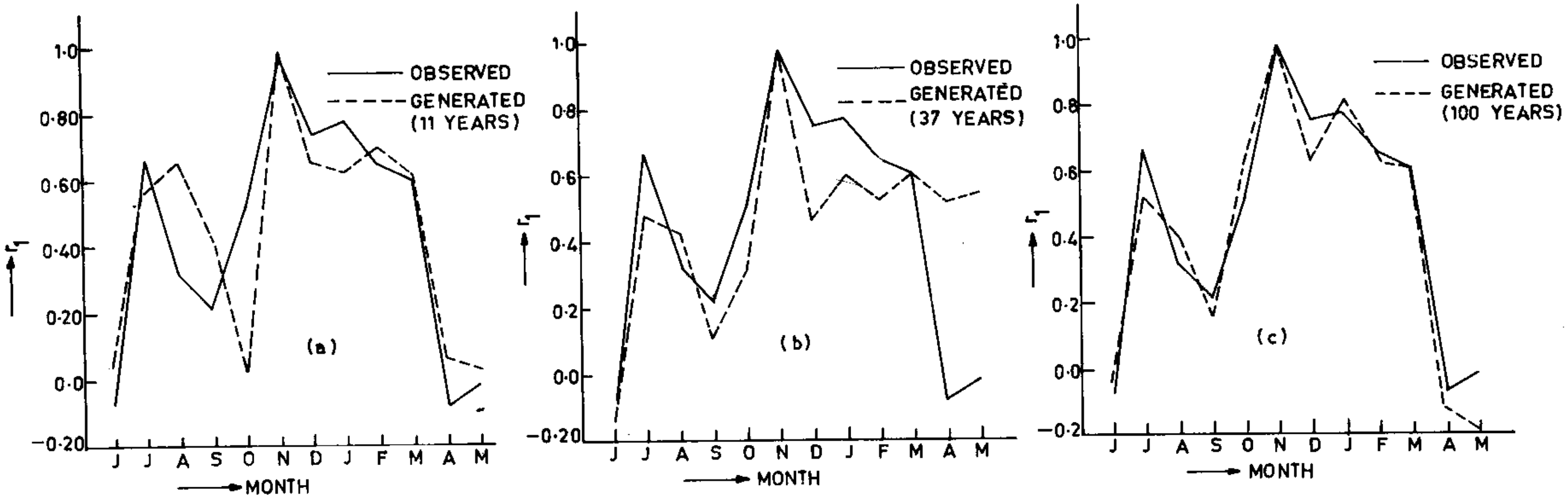


Fig.4 Comparison of correlation with previous month (r_1) of observed and generated Hirakud flows with reference to Salebhata

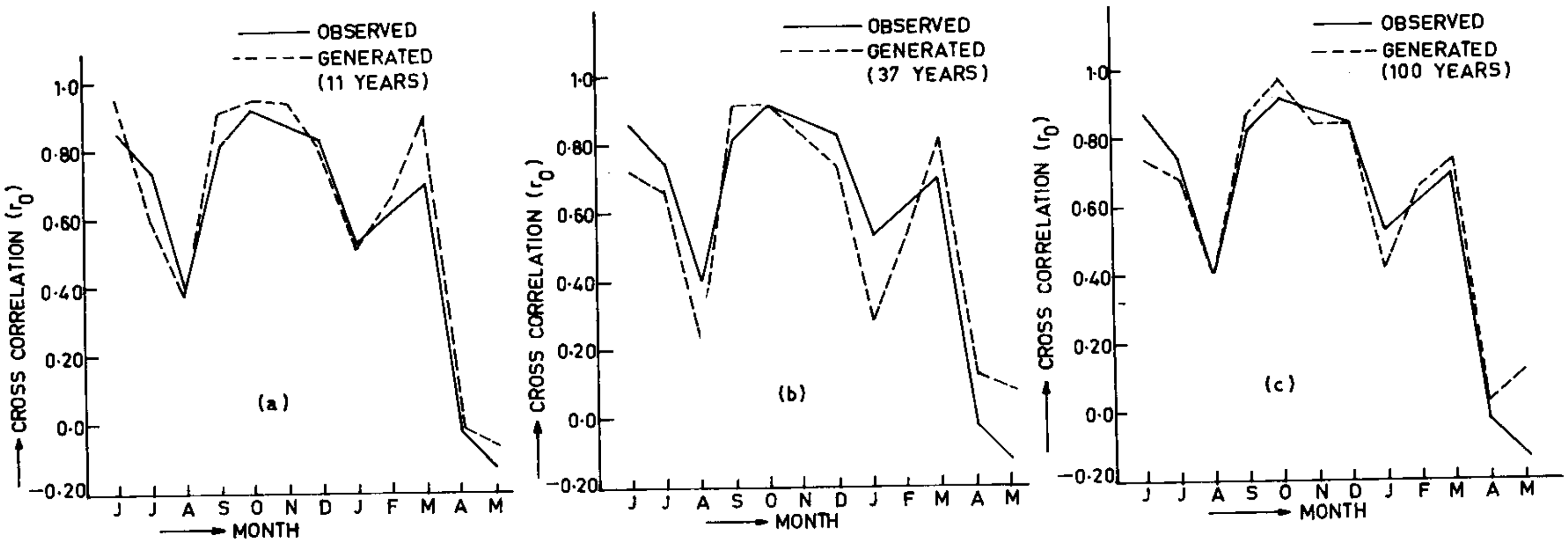


Fig.5 Comparison of observed and generated cross correlation (r_o) between Hirakud and Salebhata flows.

the corresponding flows for Hirakud) of observed (1972-82) and generated monthly flows ((i) 11 years, (ii) 37 years and (iii) 100 years) are given in table 5 and also plotted in figs.6,7, and 8. It is seen that for 11 years length of generated flows, the four parameters do not match well. The reproduction of standard deviation is very poor in case of all the three data lengths. The performance of the model is better when the generated sample is of 100 years length.

The reproduction of statistical parameters in generated flows is bivariate Thomas Fiering model and univariate Thomas Fiering model has been compared on the basis of (i) sum of squares of error in mean, R_m (ii) sum of squares of error in standard deviation R_s and (iii) absolute error in correlation with previous month, ER^1. The results are given in table 9. The values of Rm decrease as length of generated data increases. No particular trend is seen in case of R_s. The values of R_m and R_s are much lesser in case of univariate Thomas Fiering model indicating that reproduction of mean and standard deviation is better in univariate TFM.

Absolute error in reproduction of correlation with previous month in case of bivariate Thomas Fiering model (100 years) and univariate Thomas Fiering model (100 years) are 1.087 and 0.847 respectively on annual basis and 0.74 and 0.516 on monsoon basis. This indicates that preservation of correlation with previous month is also better in case of univariate Thomas Fiering model.

8.2 Monthly Streamflow Generation at Hirakud and Kantamal

8.2.1 Hirakud with reference to Kantamal

The statistical parameters(mean, standard deviation, correlation

TABLE 5: STATISTICAL PARAMETERS OF OBSERVED AND GENERATED SALEBHATA FLOWS WITH REFERENCE TO HIRAKUD

S.No.		OBSERVED 11 yr				Generated 11 yr				Generated 37 yr				Generated 100 yr			
	Month	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o
1	June	2.4	3.6	-0.368	0.868	2.6	2.5	-0.298	0.962	2.3	2.0	-0.336	0.725	2.8	2.0	-0.090	0.731
2	July	93.1	100.9	0.389	0.743	125.1	89.5	0.164	0.595	99.8	78.9	0.178	0.672	103.6	79.2	0.267	0.686
3	Aug	186.0	113.8	-0.168	0.398	236.5	80.1	0.340	0.381	211.8	88.6	-0.035	0.244	181.0	101.0	-0.064	0.410
4	Sept	85.5	73.9	-0.249	0.823	84.6	59.1	0.090	0.919	73.6	58.0	-0.076	0.923	75.8	54.5	-0.310	0.860
5	Oct	18.3	23.4	-0.020	0.920	20.4	16.8	0.062	0.953	17.6	13.8	0.267	0.916	18.9	15.8	0.195	0.894
6	Nov	5.7	5.6	0.970	0.876	5.9	4.0	0.989	0.943	5.7	3.3	0.922	0.932	5.7	4.1	0.954	0.941
7	Dec	1.3	0.8	0.763	0.853	1.3	0.6	0.493	0.806	1.5	0.6	0.402	0.735	1.4	0.8	0.685	0.947
8	Jan	1.1	0.5	0.613	0.529	1.3	0.5	0.386	0.412	1.2	0.4	0.465	0.281	1.1	0.5	0.594	0.419
9	Feb	1.4	0.6	0.561	0.622	1.3	0.5	0.539	0.671	1.4	0.4	0.464	0.530	1.4	0.5	0.487	0.618
10	Mar	1.1	0.7	0.181	0.694	1.5	0.9	0.289	0.899	1.3	0.7	0.018	0.812	1.2	0.7	0.165	0.742
11	Apr	0.6	0.2	0.634	0.030	0.7	0.2	0.924	0.008	0.7	0.2	0.685	0.131	0.6	0.2	0.666	0.026
12	May	0.2	0.2	0.306	-0.117	0.2	0.1	0.168	0.062	0.2	0.1	0.416	0.092	0.2	0.1	0.412	0.126

r_1 correlation with previous month

r_o cross correlation between Salebhata and Hirakud

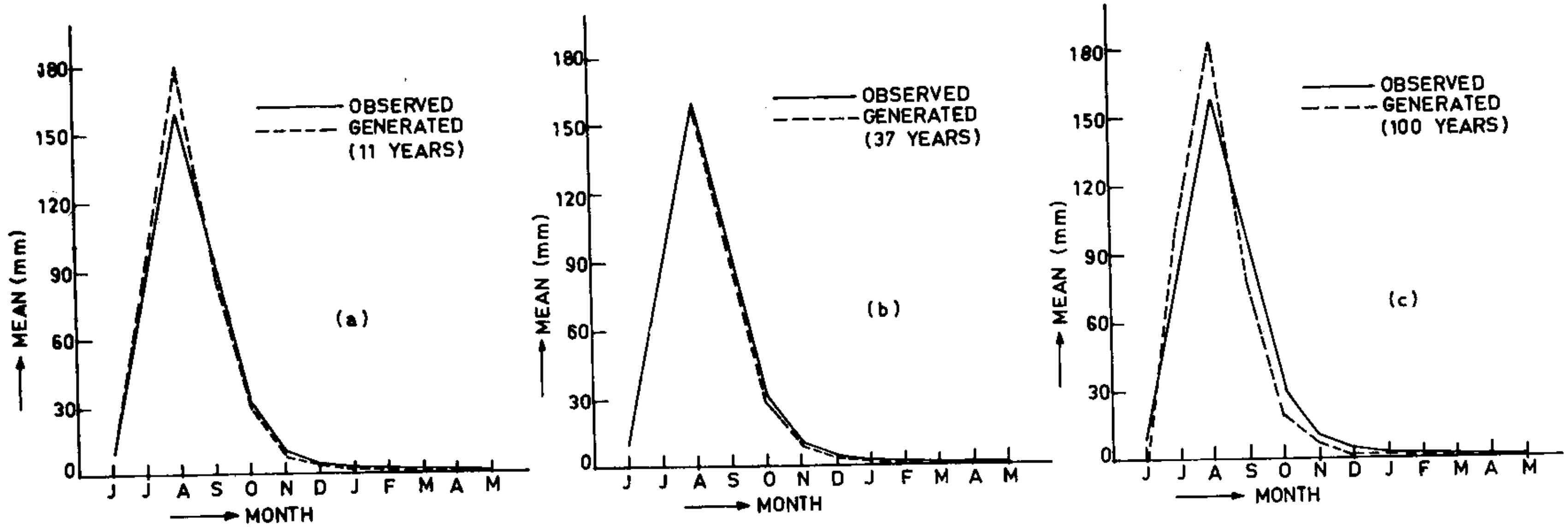


Fig. Comparison of monthly means of observed and generated Salabhata flows with reference to Hirakud.

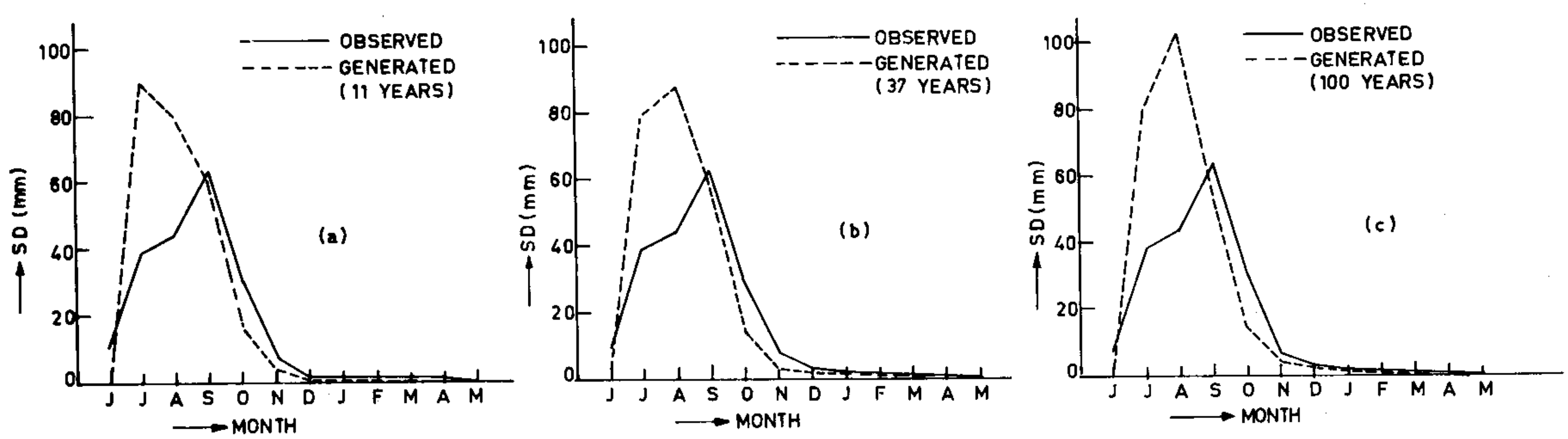


Fig.7 Comparison of monthly standard deviations of observed and generated Salebhata flows with reference to Hirakud.

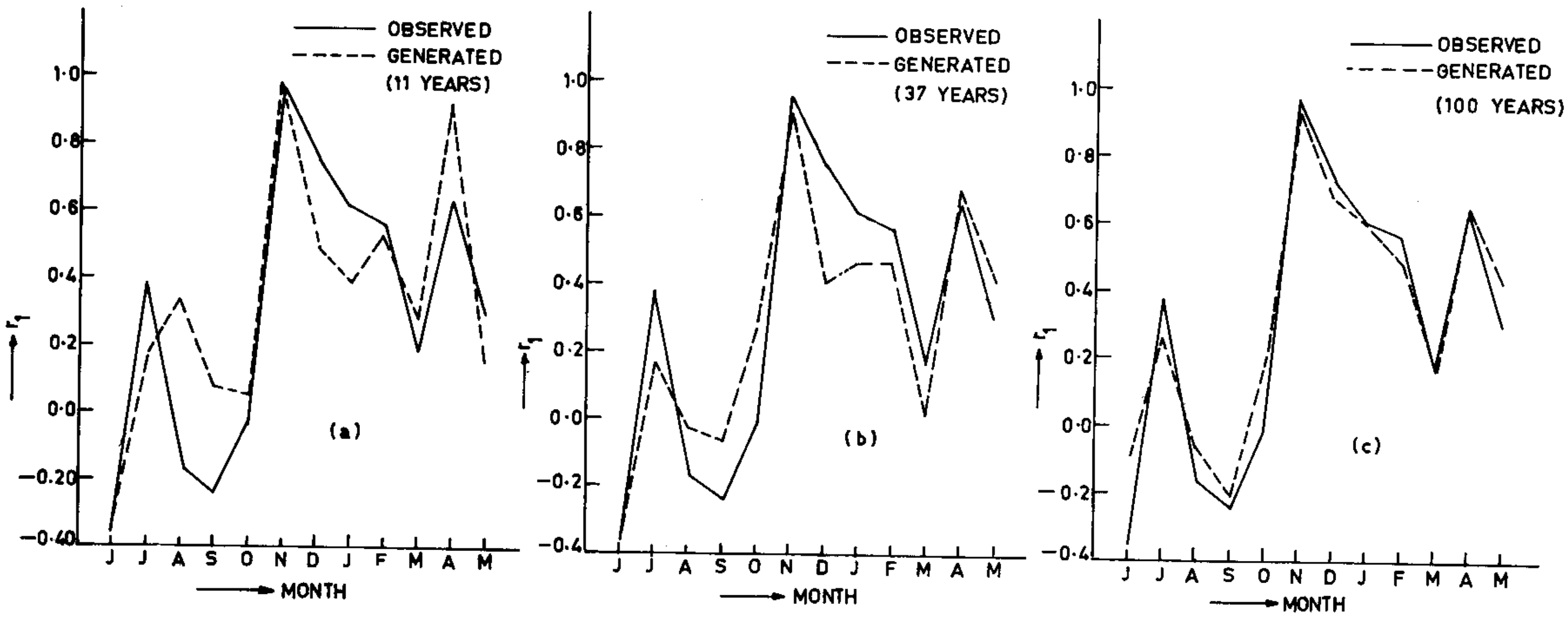


Fig.8 Comparison of correlation with previous month (r_1) of observed and generated Salebhata flows with reference to Hirakud.

TABLE 9: COMPARISON OF STATISTICAL PARAMETERS OF OBSERVED AND GENERATED MONTHLY FLOWS AT SALEBHATA ON THE BASIS OF SUM OF SQUARES OF ERROR

Sum of squares of error on		Bivariate Thomas Fiering Model (w.r.t. Hirakud)			Univariate Thomas Fiering Model
		11 yrs	37 yrs	100 yrs	100 years
Annual basis	Mean	3584.35	855.37	229.35	187.48
	S.D.	1530.36	1468.60	1066.33	116.39
Monsoon basis	Mean	3584.1	855.27	229.34	187.45
	S.D.	1527.99	1663.43	1064.15	116.37

with previous month and cross correlation with Kantamal flows) of observed (1972-82) and generated monthly flows (11 years, 37 years and 100 years) are given in Table 6 and also plotted in figs 9,10,11 and 12. It is seen that for 11 years length of generated data, the four parameters (mean, standard deviation, r_1 and r_o) do not match well. However, for 37 years and 100 years length of generated data there is good reproduction of means, though standard deviation r_o and r_1 still do not match completely. The overall performance of the model is quite good when the generated sample is of 100 years length as clearly indicated by Figs.9, 10, 11 and 12.

The monthly flows (100 years) at Hirakud have been generated using univariate Thomas Fiering model also. The reproduction of statistical parameters in generated flows in bivariate Thomas Fiering model and univariate Thomas Fiering model has been compared on the basis of (i) sum of squares of error in mean, R_m, (ii) sum of squares of error in standard deviation, R_s and (iii) absolute error in correlation with previous month. The results are given in Table 8. The values of R_m decrease as the length of generated data increases. No particular trend is seen in case of R_s. The values of R_m and R_s are much lesser in case of univariate Thomas Fiering model.

Absolute error in reproduction of correlation with previous month in case of bivariate Thomas Fiering model (100 years) and univariate Thomas Fiering model (´ 0 years) are 0.283 and 0.278 respectively on annual basis and 0.536 and 0.504 on monsoon basis. This indicates that reproduction of mean, standard deviation and correlation with previous month is somewhat better in case of univariate Thomas Fiering Model.

TABLE _: STATISTICAL PARAMETERS OF OBSERVED AND GENERATED HIRAKUD FLOWS WITH REFERENCE TO KANTAMAL

Month	Observed 11 years				Generated 11 years				Generated 37 years				Generated 100 years			
	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o
JUNE	8.6	10.6	-0.065	0.425	9.7	12.7	0.117	0.927	9.1	9.5	-0.150	0.387	10.6	9.0	-0.068	0.431
JULY	80.1	38.0	0.661	0.742	93.3	38.4	0.685	0.619	80.6	38.8	0.591	0.733	83.7	35.9	0.638	0.723
AUG	57.7	44.5	0.318	0.627	178.2	51.2	0.686	0.697	158.0	38.6	0.458	0.542	157.7	41.1	0.442	0.608
SEPT	94.0	63.5	0.213	0.699	87.2	50.8	0.320	0.843	79.4	51.2	0.105	0.823	81.5	57.8	0.152	0.701
OCT	31.5	29.7	0.520	0.893	29.7	26.1	0.046	0.963	28.1	22.9	0.334	0.913	30.4	23.7	0.592	0.855
NOV	10.2	7.4	0.982	0.935	9.7	7.5	0.985	0.989	9.1	6.3	0.979	0.928	9.7	6.4	0.974	0.927
DEC	4.6	1.5	0.735	0.923	4.4	1.4	0.761	0.939	4.8	1.4	0.566	0.905	4.6	1.4	0.649	0.915
JAN	2.3	0.8	0.772	0.591	2.7	0.8	0.618	0.694	2.5	0.7	0.682	0.538	2.4	0.7	0.810	0.560
FEB	2.0	0.8	0.652	0.579	2.3	0.9	0.751	0.736	2.0	0.7	0.582	0.550	2.0	0.8	0.636	0.622
MAR	1.2	0.8	0.602	0.606	1.6	0.9	0.648	0.637	1.3	0.7	0.486	0.668	1.3	0.7	0.571	0.661
APR	0.4	0.2	-0.081	-0.070	0.4	0.2	0.176	-0.099	0.4	0.2	-0.031	0.056	0.5	0.2	-0.132	-0.063
MAY	0.4	0.0	-0.21	0.058	0.4	0.0	0.052	0.164	0.4	0.0	-0.165	0.313	0.4	0.0	-0.233	0.378

r_1 correlation with previous month

r_o cross correlation between Hirakud and Kantamal

TABLE _: STATISTICAL PARAMETERS OF OBSERVED AND GENERATED HIRAKUD FLOWS WITH REFERENCE TO KANTAMAL

Month	Observed 11 years				Generated 11 years				Generated 37 years				Generated 100 years			
	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o	Mean	S.D.	r_1	r_o
JUNE	8.6	10.6	-0.065	0.425	9.7	12.7	0.117	0.927	9.1	9.5	-0.150	0.387	10.6	9.0	-0.068	0.431
JULY	80.1	38.0	0.661	0.742	93.3	38.4	0.685	0.619	80.6	38.8	0.591	0.733	83.7	35.9	0.638	0.723
AUG	57.7	44.5	0.318	0.627	178.2	51.2	0.686	0.697	158.0	38.6	0.458	0.542	157.7	41.1	0.442	0.608
SEPT	94.0	63.5	0.213	0.699	87.2	50.8	0.320	0.843	79.4	51.2	0.105	0.823	81.5	57.8	0.152	0.701
OCT	31.5	29.7	0.520	0.893	29.7	26.1	0.046	0.963	28.1	22.9	0.334	0.913	30.4	23.7	0.592	0.855
NOV	10.2	7.4	0.982	0.935	9.7	7.5	0.985	0.989	9.1	6.3	0.979	0.928	9.7	6.4	0.974	0.927
DEC	4.6	1.5	0.735	0.923	4.4	1.4	0.761	0.939	4.8	1.4	0.566	0.905	4.6	1.4	0.649	0.915
JAN	2.3	0.8	0.772	0.591	2.7	0.8	0.618	0.694	2.5	0.7	0.682	0.538	2.4	0.7	0.810	0.560
FEB	2.0	0.8	0.652	0.579	2.3	0.9	0.751	0.736	2.0	0.7	0.582	0.550	2.0	0.8	0.636	0.622
MAR	1.2	0.8	0.602	0.606	1.6	0.9	0.648	0.637	1.3	0.7	0.486	0.668	1.3	0.7	0.571	0.661
APR	0.4	0.2	-0.081	-0.070	0.4	0.2	0.176	-0.099	0.4	0.2	-0.031	0.056	0.5	0.2	-0.132	-0.063
MAY	0.4	0.0	-0.21	0.058	0.4	0.0	0.052	0.164	0.4	0.0	-0.165	0.313	0.4	0.0	-0.233	0.378

r_1 correlation with previous month

r_o cross correlation between Hirakud and Kantamal

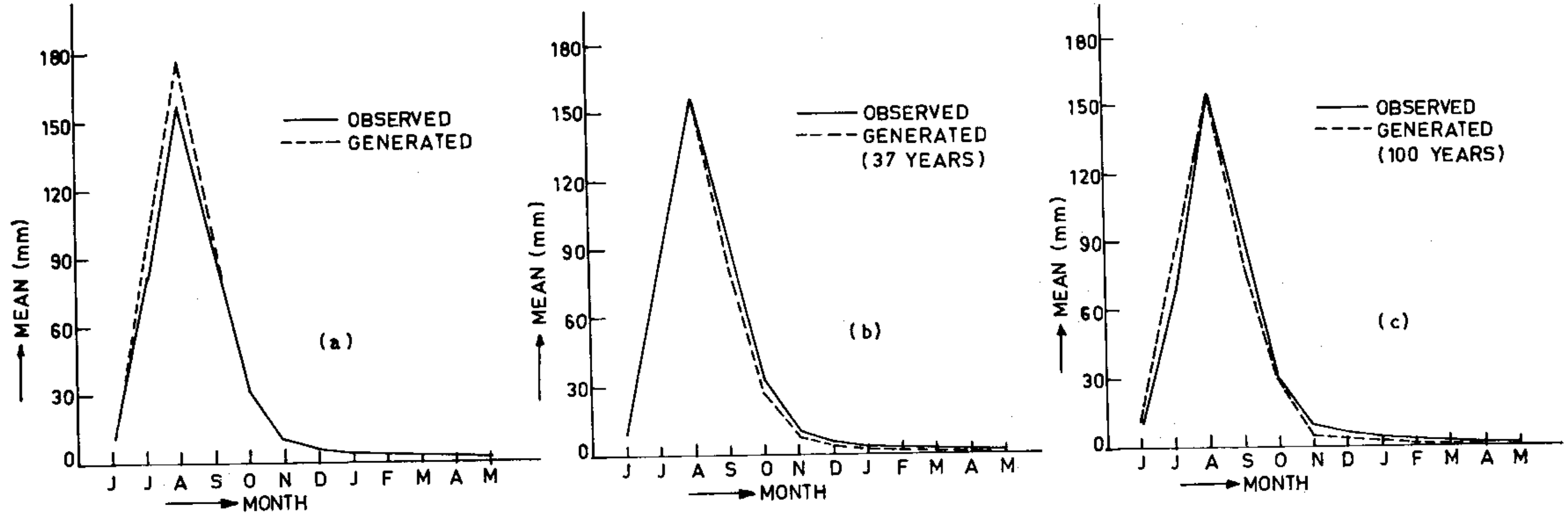
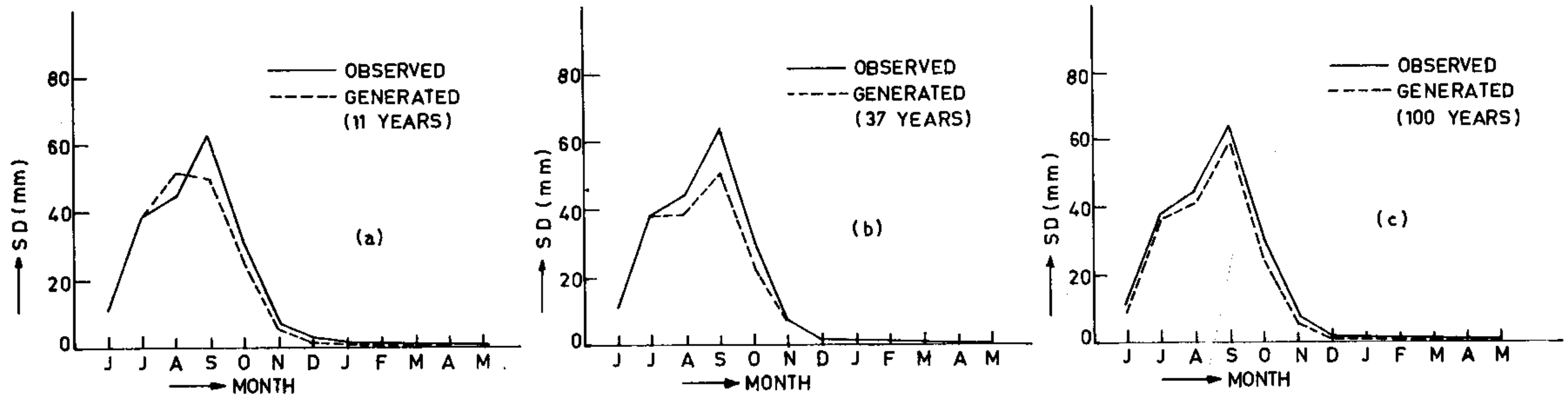


Fig.9 Comparison of monthly means of observed and generated Hirakud flows with reference to Kantamal



ig.10 Comparison of monthly standard deviations of observed and generated Hirakud flows with reference to Kantamal

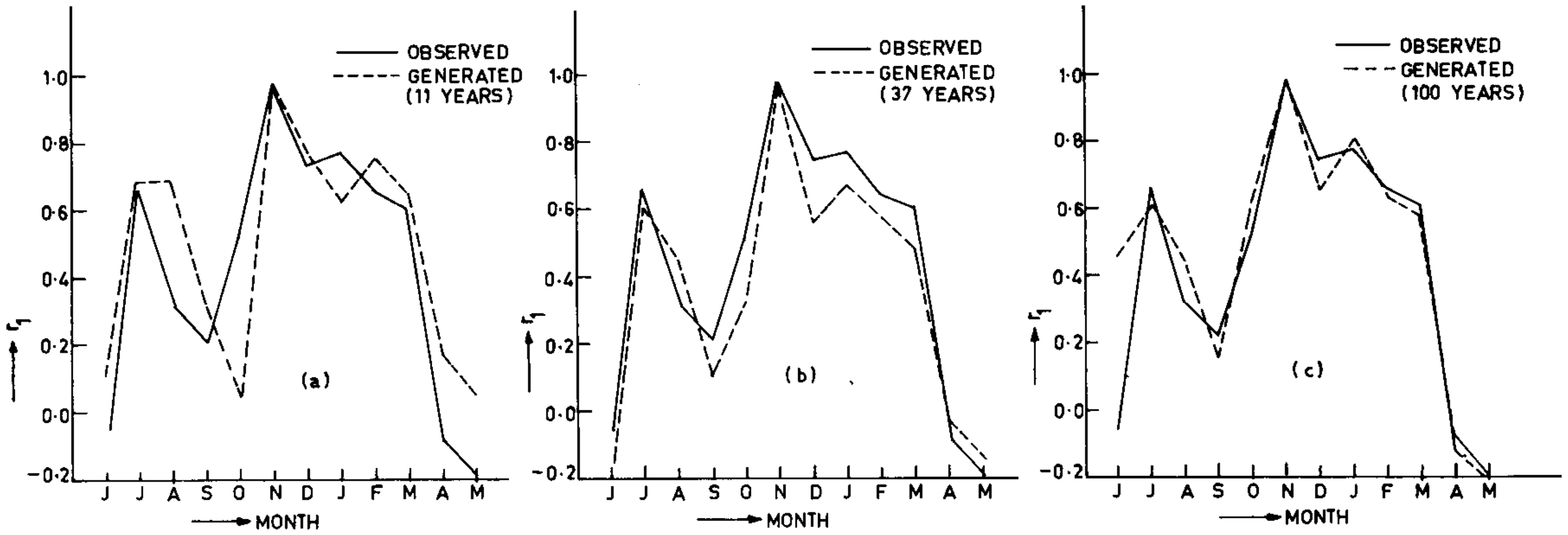


Fig.11 Comparison of correlation with previous month (r_1) of observed and generated Hirakud flows with refernece to Kantamal.

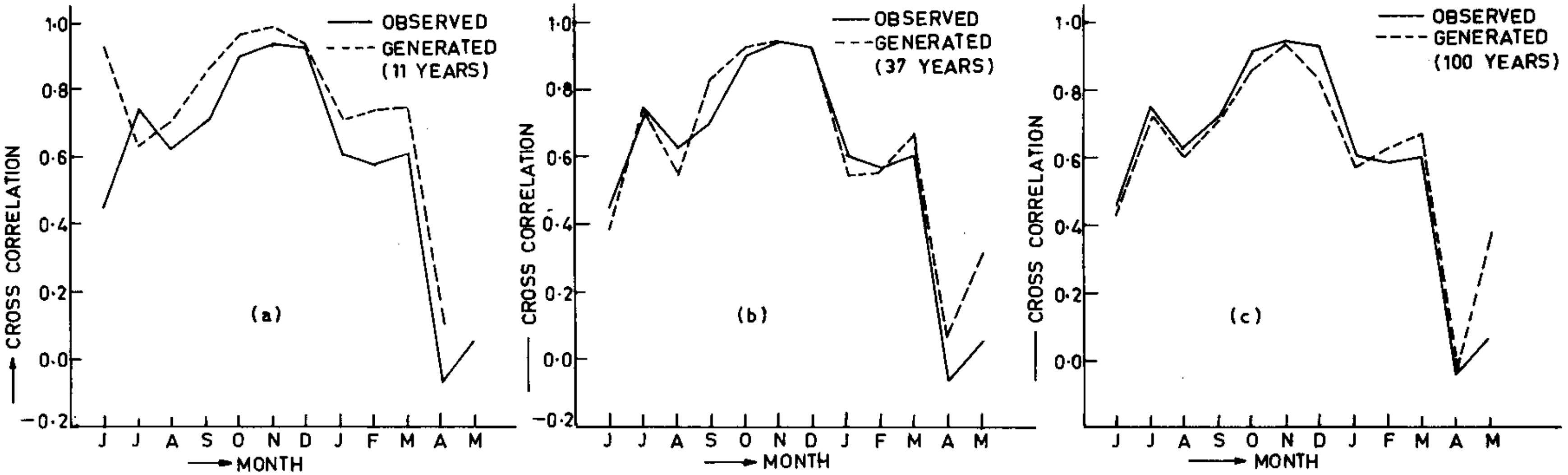


Fig.12 Comparison of observed and generated cross correlation (r_o) between Hirakud and Kantamal.

TABLE 8: COMPARISON OF STATISTICAL PARAMETERS OF OBSERVED AND GENERATED MONTHLY FLOWS AT HIRAKUD ON THE BASIS OF SUM OF SQUARES OF ERROR

Sum of squares of error on		Bivariate Thomas Fiering Model(Salebhata) W.R.t.			Bivariate Thomas Fiering model (Kantamal)			Univariate Thomas Fiering model 100 years
		11 yrs	37 yrs	100 yrs	11 yrs	37 yrs	100 yrs	
Annual basis	Mean	666.45	215.81	140.16	644.54	225.09	172.71	59.62
	S.D.	185.62	299.02	160.75	223.37	234.46	88.24	50.41
Monsoon basis	Mean	665.90	215.20	139.88	643.90	223.76	172.45	59.43
	S.D.	185.54	298.81	159.41	223.34	233.25	87.11	50.30

8.2.2 Kantamal with reference to Hirakud

The statistical parameters (mean, standard deviation, correlation with previous month and cross correlation with Hirakud) are given in Table 7 and plotted in figure 13,14,15 and 12.

The monthly flows (100 years) at Hirakud have been generated using univariate Thomas Fiering model also. The reproduction of statistical parameters in generated flows in bivariate Thomas Fiering model and univariate Thomas Fiering model has been compared on the basis of (i) sum of squares of error in mean, R_m (ii) sum of squares of error in standard deviation, R_s and (iii) absolute error in correlation with previous month. The results are given in Table 10. The values of R_m decrease as the length of generated data increases. No particular trend is seen in case of R_s. The values of R_m and R_s are much lesser in case of univariate Thomas Fiering model.

Absolute error in reproduction of correlation with previous month in case of bivariate Thomas Fiering model (100 years) and univariate Thomas Fiering model (100 years) are 0.32 and 0.571 respectively on annual basis and 0.519 and 0.774 on monsoon basis. This indicates that reproduction of mean and standard deviation is better in case of univariate Thomas Fiering model. Reproduction of correlation with previous month is, however, better in bivariate Thomas Fiering model for this particular site.

Table 7: STATISTICAL PARAMETERS FOR OBSERVED AND GENERATED KANTAMAL FLOWS WITH REFERENCE TO HIRAKUD

S.No.	Month	ORIGINAL 11 yr Mean	S.D.	r_1	r_o	Generated 11 yr Mean	S.D.	r_1	r_o	Generated 37 yr Mean	S.D.	r_1	r_o	Generated 100 yr Mean	S.D.	r_1	r_o
1	June	9.7	13.5	-0.336	0.424	11.5	9.9	0.118	0.927	9.8	10.1	-0.101	0.307	12.0	10.5	0.227	0.431
2	July	102.8	83.8	0.281	0.742	129.1	78.3	0.423	0.619	106.3	73.5	0.191	0.733	110.8	73.1	0.273	0.723
3	Aug	177.3	124.6	-0.055	0.627	254.2	106.2	0.466	0.697	209.4	94.4	0.056	0.542	179.5	110.4	0.017	0.608
4	Sept	118.4	86.2	-0.013	0.698	122.6	76.3	0.244	0.843	109.1	71.6	0.178	0.823	105.9	61.4	-0.025	0.701
5	Oct	22.5	15.1	-0.194	0.893	21.0	12.7	-0.176	0.963	20.9	10.0	-0.003	0.913	21.5	12.2	-0.075	0.855
6	Nov	11.7	9.9	0.867	0.936	10.9	9.4	0.951	0.989	11.1	8.0	0.877	0.928	11.4	8.1	0.836	0.927
7	Dec	4.7	2.0	0.742	0.919	4.6	1.8	0.804	0.937	5.1	1.8	0.657	0.905	4.8	1.9	0.731	0.915
8	Jan	1.8	0.9	0.728	0.598	1.9	0.6	0.674	0.694	1.9	0.8	0.745	0.536	1.8	0.8	0.708	0.560
9	Feb	0.9	0.4	0.745	0.574	0.8	0.4	0.764	0.736	0.9	0.4	0.802	0.550	0.9	0.4	0.740	0.622
10	Mar	0.5	0.5	0.542	0.617	0.7	0.6	0.751	0.837	0.7	0.4	0.480	0.668	0.6	0.5	0.530	0.661
11	Apr	0.2	0.3	0.614	0.017	0.3	0.3	0.912	-0.099	0.3	0.2	0.619	0.056	0.3	0.2	0.647	-0.683
12	May	0.3	0.5	0.084	0.058	0.3	0.3	0.064	0.164	0.4	0.3	0.200	0.313	0.4	0.4	0.171	0.378

r_1 Correlation with previous month

r_o Cross-correlation between Kantamal and Hirakud

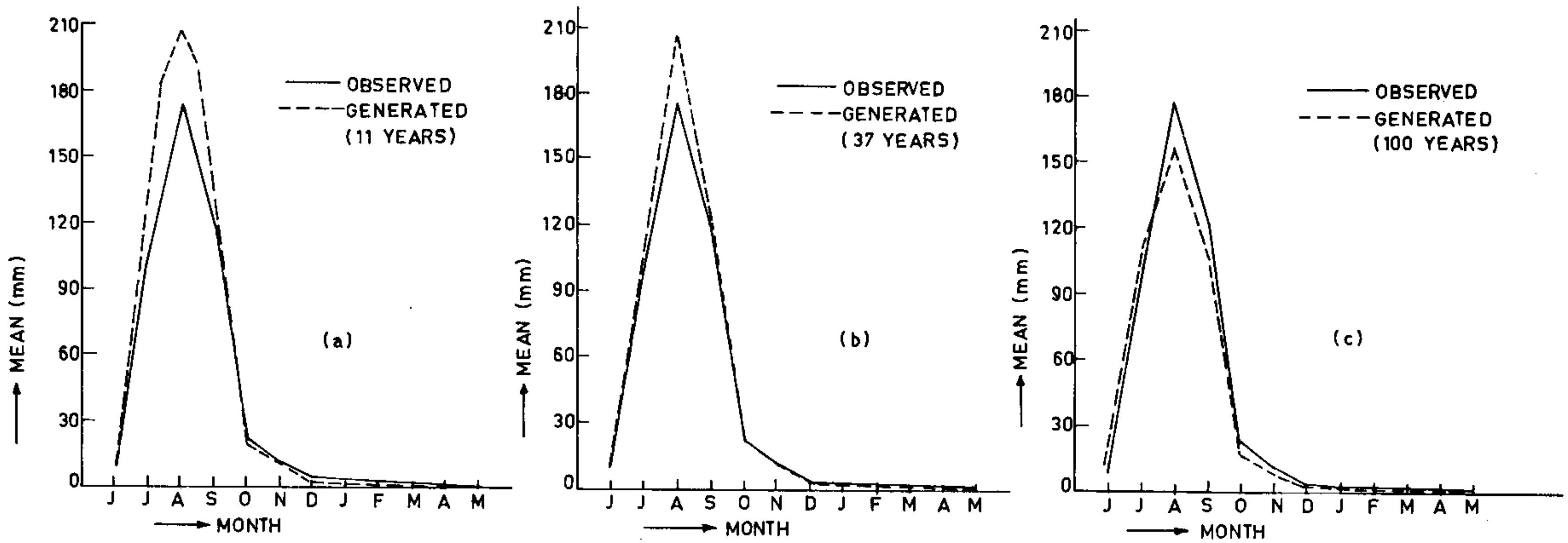


Fig13 Comparison of monthly means of observed and generated Kantamal flows with reference to Hirakud.

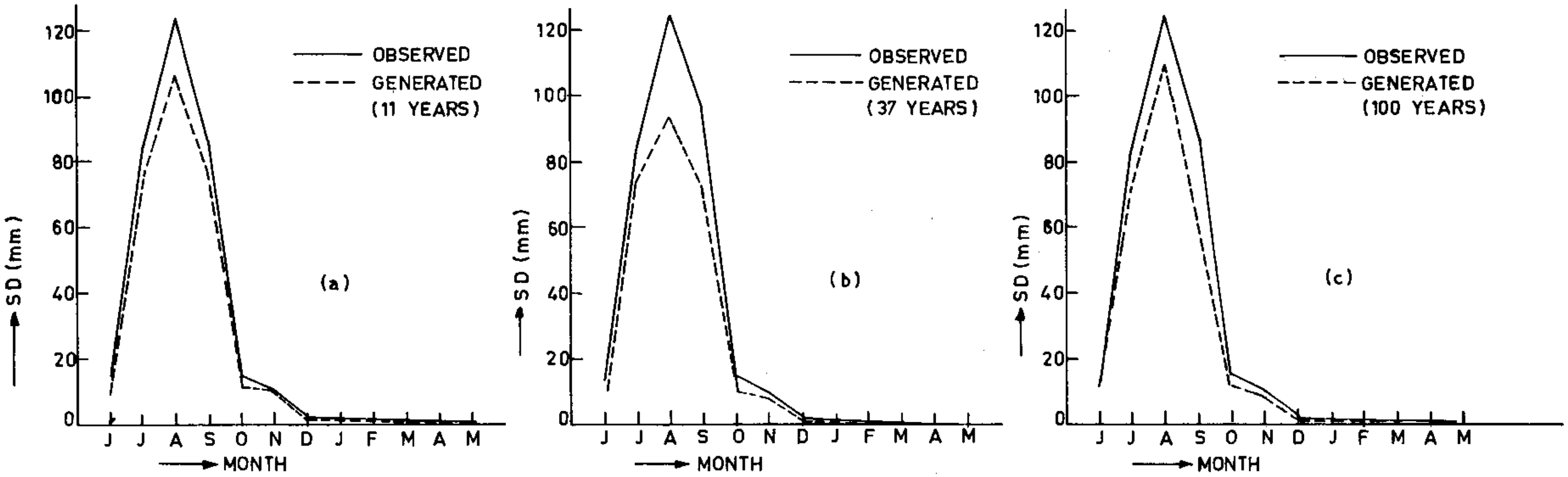


Fig. 14 Comparison of monthly standard deviations of observed and generated Kantamal flows with reference to Hirakud.

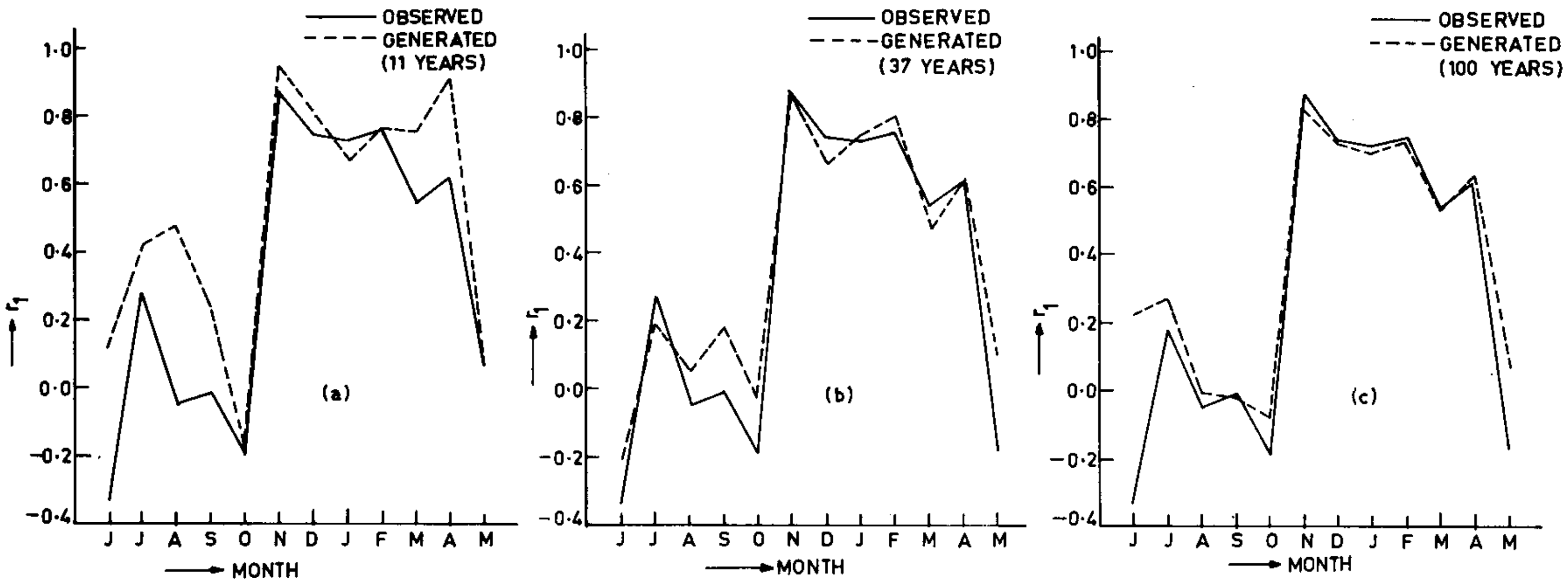


Fig.15 Comparison correlation with previous month (r_1) of observed and generated Kantamal flows with to Hirakud.

TABLE 10: COMPARISON OF STATISTICAL PARAMETERS OF OBSERVED AND GENERATED MONTHLY FLOWS AT KANTAMAL ON THE BASIS OF SUM OF SQUARES OF ERROR

Sum of Squares of error on		Bivariate Thomas Fiering Model (w.r.t. Hirakud)			Univariate Thomas Fiering Model
		11 yrs	37 yrs	100 yrs	100 years
Annual basis	Mean	6623.00	1134.16	230.59	263.13
	S.D.	488.04	1275.51	954.94	203.29
Monsoon basis	Mean	6622.29	1133.70	230.47	263.13
	S.D.	487.64	1271.81	951.66	203.24

9.0 CONCLUSION

The computer programme for bivariate Thomas Fiering model developed on the basis of algorithm given by Clarke (1973) and implemented on the VAX 11/780 computer has provided reasonably satisfactory results for simultaneous generation of monthly streamflows for a pair of two sites. The results are satisfactory both for Hirakud-Salebhata pair and Hirakud-Kantamal pair. It is seen that as the length of generated flow sequence increases from 11 to 37 to 100 years, the reproduction of statistical parameters of the observed flow series (11 years) improves.

The comparison of performance of bivariate model with the univariate model indicates somewhat better performance for the univariate model in the reproduction of mean and standard deviation. This seems to be due to somewhat limited length of data i.e.11 years being used and also poor cross correlation for monthly flows of August which contributes quite a high proportion of flow.

However, in order to judge, the relative performance of bivariate and univariate models, it would be desirable that further investigations are carried out for more sites with better data base. The use of bivariate Thomas Fiering model should generally be preferred over univariate Thomas Fiering model since it would enable preservation of not only statistical characteristics of the particular sites but also the cross correlation structure with the other site.

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APPENDIX I

```
C       THIS PROGRAM IS MEANT FOR BIVARIATE EXTENSION OF THE THOMAS
C       FIERING METHOD
C       MONTHLY STREAMFLOW DATA IS REQUIRED
C       X1 , X2 : MONTHLY STREAMFLOWS
C       MEAN1(J) : MEAN OF MONTH J FOR STATION 1
C       MEAN2(J) : MEAN OF MONTH J FOR STATION 2
C       SD1(J)   : STANDARD DEVIATION OF MONTH J FOR STATION 1
C       SD2(J)   : STANDARD DEVIATION OF MONTH J FOR STATION 2
C       Y11(I,J),Y12(I,J),... : STANDARDISED MONTHLY FLOWS
C       SUM1(11,SUM1112,..... : QUANTITIES TO BE ESTIMATED
C       B11(JJ),B12(JJ),..... : MODEL PARAMETERS FOR MONTH JJ
C       U1 , U2  : PSEUDO - RANDOM NORMAL DEVIATES GENERATED BY THE
C       BOX-MULLER METHOD
C       Y1(I,JJ) : THE GENERATED SEQUENCE FOR STATION 1 , MONTH 'JJ'
C       AND Ith YEAR
C       Y2(I,JJ) : THE GENERATED SEQUENCE FOR STATION 2 , MONTH 'JJ'
C       AND Ith YEAR
C       N : NUMBER OF YEARS FOR WHICH DATA IS AVAILABLE
C       N1 : NUMBER OF YEARS FOR WHICH SYNTHETIC DATA IS REQUIRED
        REAL MEAN1,MEAN2
        DIMENSION MEAN1(12),MEAN2(12),SD1(12),SD2(12),X2(100,12),
        1Y21(100,12),Y22(100,12),B11(12),B12(12),B21(12),B22(12),
        2Y1(100,12),Y2(100,12),Y11(100,12),Y12(100,12),X1(100,12)
        DIMENSION VARZI1(12),VARZI2(12),COZI12(12),Y3(100,12),Y4(100,12)
        DIMENSION CV1(12),CV2(12),NYEAR(80),TITLE1(80),TITLE2(80)
        DIMENSION OX1(1200),OX2(1200),GY3(1200),GY4(1200),CROSS(12)
        DIMENSION GMEAN1(12),GMEAN2(12),GSD1(12),GSD2(12)
        COMMON ZR(12),ZR(12)
        OPEN(UNIT=1,FILE='THOMAS.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='THOMAS.OUT',STATUS='NEW')
        ACCEPT *,N,N1
C       CALL DATA
        READ(1,1000)TITLE1
        READ(1,*)((NYEAR(I),(X1(I,J),J=1,12),Q1,Q2,Q3),I=1,N)
        READ(1,1000)TITLE2
1000    FORMAT(80A1)
        READ(1,*)((NYEAR(I),(X2(I,J),J=1,12),Q1,Q2,Q3),I=1,N)
        DO 1010 L=1,N
        DO 1020 J=1,12
        I=12*(L-1)+J
        OX1(I)=X1(L,J)
1020    OX2(I)=X2(L,J)
1010    CONTINUE
        WRITE(2,1000)TITLE1
        WRITE(2,1030)(NYEAR(I),(X1(I,J),J=1,12),I=1,N)
1030    FORMAT(I5,12F8.1)
        CALL EXAM(OX1,N,MEAN1,SD1)
        WRITE(2,1000)TITLE2
        WRITE(2,1040)(NYEAR(I),(X2(I,J),J=1,12),I=1,N)
1040    FORMAT(I5,12F8.1)
```

```
      CALL EXAM(OX2,N,MEAN2,SD2)
      CALL CROSS1(X1,X2,N,MEAN1,MEAN2,SD1,SD2,CROSS)
      AN=N
      DO 6 J=1,12
      JJ=J+1
C     IF(J.EQ.2) JJ=1
      IF(J.EQ.12) JJ=1
      DO 7 I=1,N
      Y11(I,J)=(X1(I,J)-MEAN1(J))/SD1(J)
      Y12(I,J)=(X2(I,J)-MEAN2(J))/SD2(J)
      Y21(I,J)=(X1(I,JJ)-MEAN1(JJ))/SD1(JJ)
7     Y22(I,J)=(X2(I,JJ)-MEAN2(JJ))/SD2(JJ)
C     WRITE(2,500)
500   FORMAT(/1X,'STANDARD VARIABLES'/)
C     WRITE(2,100)(Y21(I,J),Y22(I,J),Y11(I,J),Y12(I,J),I=1,N)
100   FORMAT(5X,4F12.3)
      SM1111=0.0
      SM1122=0.0
      SM1112=0.0
      DO 8 I=1,N
      SM1111=SM1111+Y11(I,J)**2
      SM1122=SM1122+Y12(I,J)**2
      SM1112=SM1112+Y11(I,J)*Y12(I,J)
8     CONTINUE
      SM1111=SM1111/AN
      SM1122=SM1122/AN
      SM1112=SM1112/AN
      WRITE(2,250)
250   FORMAT(/1X,'SIGMA(11) = ',5X)
      WRITE(2,600) SM1111,SM1112,SM1112,SM1122
      A=SM1111*SM1122
      B=SM1112*SM1112
      DELTA=A-B
C     WRITE(2,700)DELTA
600   FORMAT(2F8.3/2F8.3)
      SM2211=0.0
      SM2212=0.0
      SM2222=0.0
      DO 9 I=1,N
      SM2211=SM2211+Y21(I,J)*Y21(I,J)
      SM2212=SM2212+Y21(I,J)*Y22(I,J)
      SM2222=SM2222+Y22(I,J)*Y22(I,J)
9     CONTINUE
      SM2211=SM2211/AN
      SM2212=SM2212/AN
      SM2222=SM2222/AN
      WRITE(2,350)
350   FORMAT(/1X,'SIGMA(22) = ',5X)
      WRITE(2,600) SM2211,SM2212,SM2212,SM2222
      SM2111=0.0
```

```
      SM2112=0.0
      SM2121=0.0
      SM2122=0.0
      DO 10 I=1,N
      SM2111=SM2111+Y21(I,J)*Y11(I,J)
      SM2112=SM2112+Y21(I,J)*Y12(I,J)
      SM2121=SM2121+Y22(I,J)*Y11(I,J)
      SM2122=SM2122+Y22(I,J)*Y12(I,J)
10    CONTINUE
      SM2111=SM2111/AN
      SM2112=SM2112/AN
      SM2121=SM2121/AN
      SM2122=SM2122/AN
      WRITE(2,451)
451   FORMAT(/1X,'SIGMA(12) = ',5X)
      WRITE(2,600) SM2111,SM2112,SM2121,SM2122
C     DELTA=SM1111*SM1122-SM1121*SM1112
C     WRITE(2,700)DELTA
700   FORMAT(/5X,'DELTA = ',F6.3/)
      B11(JJ)=(SM2111*SM1122-SM2112*SM1112)/DELTA
      B12(JJ)=(SM1111*SM2112-SM2111*SM1112)/DELTA
      B21(JJ)=(SM2121*SM1122-SM2122*SM1112)/DELTA
      B22(JJ)=(SM1111*SM2122-SM2121*SM1112)/DELTA
      VARZI1(JJ)=SM2211-B11(JJ)*SM2111-B12(JJ)*SM2112
      VARZI2(JJ)=SM2222-B21(JJ)*SM2121-B22(JJ)*SM2122
      COZI12(JJ)=SM2212-B11(JJ)*SM2121-B12(JJ)*SM2122
      WRITE(2,800) B11(JJ),B12(JJ),B21(JJ),B22(JJ)
800   FORMAT(/5X,'B11 =',F7.3,3X,'B12 =',F7.3,3X,'B21 =',F7.3,3X,'B22
     1 =',F7.3)
      WRITE(2,850)
850   FORMAT(/1X,'VARIANCE(1) , VARIANCE(2) AND COVARIANCE'/)
      WRITE(2,900) VARZI1(JJ),VARZI2(JJ),COZI12(JJ)
900   FORMAT(5X,3F10.3)
6     CONTINUE
      DO 11 L=1,N1
      DO 12 J=1,12
      IF(L.EQ.1.AND.J.EQ.1) Y1(L,12)=0.0
      IF(L.EQ.1.AND.J.EQ.1) Y2(L,12)=0.0
      CALL BOXMUL(U1,U2,1,IX,IY)
      K=J-1
      IF(J.EQ.1) K=12
      ZI21=U1*SQRT(VARZI1(J))
      ZI22=U1*(COZI12(J)/SQRT(VARZI1(J)))+U2*(SQRT(VARZI2(J)-COZI12(J)**2/
     1VARZI1(J)))
      Y1(L,J)=B11(J)*Y1(L,K)+B12(J)*Y2(L,K)+ZI21
      Y2(L,J)=B21(J)*Y1(L,K)+B22(J)*Y2(L, K)+ZI22
      Y3(L,J)=Y1(L,J)*SD1(J)+MEAN1(J)
      IF(Y3(L,J).LT.0.) Y3(L,J)=0.
      Y4(L,J)=Y2(L,J)*SD2(J)+MEAN2(J)
      IF(Y4(L,J).LT.0.) Y4(L,J)=0.
```

```
12      CONTINUE
11      CONTINUE
        DO 1050 L=1,N1
        DO 1060 J=1,12
        I=12*(L-1)+J
        GY3(I)=Y3(L,J)
1060    GY4(I)=Y4(L,J)
1050    CONTINUE
        WRITE(2,950)
950     FORMAT(/1X,'GENERATED SEQUENCE'/)
        WRITE(2,961)
961     FORMAT(/1X,'HIRAKUD GENERATED FLOWS'/)
        WRITE(2,960)((Y3(L,J),J=1,12),L-1,N1)
960     FORMAT(1X,12F8.1)
        CALL EXAM(GY3,N1,GMEAN1,GSD1)
        WRITE(2,962)
962     FORMAT(/1X,'NARAJ GENERATED FLOWS'/)
        WRITE(2,960) ((Y4(L,J),J=1,12),L=1,N1)
        CALL EXAM(GY4,N1,GMEAN2,GSD2)
        ANMEAN1=0.0
        ANMEAN2=0.0
        ANSD1=0.0
        ANSD2=0.0
        XMONMEAN1=0.0
        XMONMEAN2=0.0
        XMONSD1=0.0
        XMONSD2=0.0
        DO 2010 I=1,12
        ANMEAN1=ANMEAN1+(MEAN1(I)-GMEAN1(I))**2
        ANMEAN2=ANMEAN2+(MEAN2(I)-GMEAN2(I))**2
        ANSD1=ANSD1+(SD1(I)-GSD1(I))**2
        ANSD2=ANSD2+(SD2(I)-GSD2(I))**2
2010    CONTINUE
        DO 2020 I=1,5
        XMONMEAN1=XMONMEAN1+(MEAN1(I)-GMEAN1(I))**2
        XMONMEAN2=XMONMEAN2+(MEAN2(I)-GMEAN2(I))**2
        XMONSD1=XMONSD1+(SD1(I)-GSD1(I))**2
        XMONSD2=XMONSD2+(SD2(I)-GSD2(I))**2
2020    CONTINUE
        WRITE(13,2030)(ANMEAN1,ANMEAN2,ANSD1,ANSD2,XMONMEAN1,XMONMEAN2
        1,XMONSD1,XMONSD2)
2030    FORMAT(//1X,'ANN. SUM OF SQUARES OF ERROR IN MEAN1 FOR SITE1=
        1'F13.2/1X'ANN. SUM OF SQUARES OF ERROR IN MEAN FOR SITE2='F13.2
        2/1X'ANN. SUM OF SQUARES OF ERROR IN SD FOR SITE1='F13.2/1X'ANN
        3. SUM OF SQUARES OF ERROR IN SD FOR SITE 2='F13.2/1X'MON. SUM
        4OF SQUARES OF ERROR IN MEAN FOR SITE1='F13.2/1X'MONSON SUM OF
        5SQUARES OF ERROR IN MEAN FOR SITE2'F13.2/1X'MON. SUM OF SQUAR
        6ES OF ERROR IN SD FOR SITE1='F13.2/1X'MON. SUM OF SQUARES OF
        7 ERROR IN SD FOR SITE2='F13.2)
        CALL CROSS1(Y3,Y4,N1,GMEAN1,GMEAN2,GSD1,GSD2,CROSS)
```

```
      STOP
      END
C     SUBROUTINE BOXMULLER
      SUBROUTINE BOXMUL(ONE,TWO,N,IX,IY)
      DIMENSION ONE(1),TWO(1)
      DO 10 I=1,N
10    CALL WHITE(IX,IY,ONE(I),TWO(I))
      RETURN
      END
C     SUBROUTINE WHITE
      SUBROUTINE WHITE(KX,KY,A,B)
      IX=831
      CALL RANDU(IX,IY,X1)
      R=X1*6.2831853
      CALL RANDU(IX,IY,X2)
      S=X2
      A=SQRT(-2.*ALOG(S))
      B=A*SIN(R)
      A=A*COS(R)
      RETURN
      END
      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
5     IY=IY+2147483647+1
6     YFL=IY
      YFL=YFL*0.4656613E-9
      IFL=YFL
      YFL=YFL-FLOAT(IFL)
      RETURN
      END
      SUBROUTINE DATA
      DIMENSION X1(100,12),X2(100,12)
      CHARACTER*80 TITLE
      COMMON X1,X2,N,N1
      DO 10 I=1,N
      READ(1,50)TITLE
      DO 1 J=1,12
1     READ(1,100) X1(I,J),X2(I,J)
      WRITE(2,60)TITLE
      WRITE(2,200)(X1(I,J),J=1,12)
      WRITE(2,300)(X2(I,J),J=1,12)
10    CONTINUE
      WRITE(2,400)
50    FORMAT(A80)
60    FORMAT(/A80/)
100   FORMAT(F10.3,40X,F10.3)
200   FORMAT(1X,'HIRAKUD',5X,6F10.3,/13X,6F10.3)
300   FORMAT(/1X,'NARAJ',7X,6F10.3/13X,6F10.3)
400   FORMAT(/78(1H*)//)
```

```
      RETURN
      END
      SUBROUTINE EXAM(Q,NYEARS,AVEMON,SDMON)
C     A SUBROUTINE TO CALCULATE MONTHLY MEANS,SD,SLOPES
C     AND CORRELATIONS START CYCLE BY LOADING 12TH MONTH
      COMMON ZB(12),ZR(12)
      DIMENSION Q(1),WORKI(100),WORKJ(100),AVEMON(12),SDMON(12)
      N=NYEARS*12
      DO 20 I=12,N,12
      J=I/12
20    WORKI(J)=Q(I)
      CALL BASIC(WORKI,AVEMON(12),SDMON(12),NYEARS)
      DO 21 I=1,12
      M=I-1
      IF (M.EQ.0) M=12
      DO 22 J=I,N,12
      K=(J+11)/12
22    WORKJ(K)=Q(J)
      CALL BASIC (WORKJ,AVEMON(I),SDMON(I),NYEARS)
      IF (I-1) 24,25,24
25    NYEARS=NYEARS-1
      A=WORKJ(1)
      DO 26 IJ=1,NYEARS
26    WORKJ(IJ)=WORKJ(IJ+1)
24    CALL CORREL(WORKI,WORKJ,AVEMON(M),AVEMON(I),SDMON(M),
     1SDMON(I),ZB(I),ZR(I),NYEARS)
      IF (I-1) 27,28,27
28    NYEARS=NYEARS+1
      DO 29 IJ=1,NYEARS-1
      IK=NYEARS-IJ
29    WORKJ(IK)=WORKJ(IK-1)
      WORKJ(1)=A
27    DO 23 K=1,NYEARS
23    WORKI(K)=WORKJ(K)
21    CONTINUE
C     OUTPUT THIS INFORMATION FOR CHECKING
      WRITE(2,106) AVEMON
      WRITE(2,114) SDMON
      WRITE(2,107) ZB
      WRITE(2,115) ZR
106   FORMAT(//' MEANS'/5X,12F8.1)
114   FORMAT(//' STANDARD DEVIATIONS'/5X,12F8.1)
107   FORMAT(//' SLOPES'/5X,12F8.3)
115   FORMAT(//' CORRELATION WITH PREVIOUS MONTH'/5X,12F8.3)
      RETURN
      END
      SUBROUTINE BASIC(X,AVER,SD,N)
      DIMENSION X(1)
C     THIS SUBROUTINE EVALUATES THE MEAN AND STANDARD DEVIATION
C     OF AN INPUT SERIES X,LENGTH N)
```

```
      SX=0.0
      SSX=0.0
      RN=1.0/FLOAT(N)
      DO 1 I=1,N
      A=X(I)
      SX=SX+A
    1 SSX=SSX+A*A
      AVER=SX*RN
      SD=SSX-SX*AVER
      SD=SQRT(SD/FLOAT(N-1))
      RETURN
      END
      SUBROUTINE CORREL (X,Y,XMEAN,YMEAN,SDX,SDY,SLOPE,R,N)
      DIMENSION X(1),Y(1),WX(100),WY(100)
C     THIS SUBROUTINE GIVES THE SLOPE OF THE FIT WHEN Y IS
C     REGRESSED ON X,ALSO R,THE CORRELATION COFFICIENT BETWEEN
C     X AND Y.
C     MEANS AND SD'S ASSUMED FROM EARLIAR WORK
      DO 1 I=1,N
      WX(I)=X(I)-XMEAN
    1 WY(I)=Y(I)-YMEAN
      SSX=0.0
      SXY=0.0
      SSY=0.0
      DO 2 I=1,N
      A=WX(I)
      B=WY(I)
      SXY=SXY+A*B
      SSX=SSX+A*A
    2 SSY=SSY+B*B
      SSX=SQRT(SSX)
      SSY=SQRT(SSY)
      R=SXY/(SSX*SSY)
      SLOPE=R*SSY/SSX
      RETURN
      END
      SUBROUTINE CROSS1 (X1,X2,N,AMEAN1,AMEAN2,SD1,SD2,CROSS)
      DIMENSION X1(100,12),X2(100,12),AMEAN1(12),AMEAN2(12),SD1(12)
     1,SD2(12),CROSS(12)
      DO 10 J=1,12
      SUM=0.0
      DO 20 I=1,N
   20 SUM=SUM+(X1(I,J)-AMEAN1(J))*(X2(I,J)-AMEAN2(J))
      CROSS(J)=SUM/(SD1(J)*SD2(J)*(N-1))
   10 CONTINUE
      WRITE(2,5)(CROSS(J),J=1,12)
    5 FORMAT(/' CROSS CORRELATION BETWEEN SITES'/5X,12F8.3)
      RETURN
      END
```

MONTHLY FLOWS IN MM AT HIRAKUD 1972-1982

1972	1.8	63.6	107.5	82.0	21.1	10.4	6.6	2.3	2.1	1.2	1.0	0.4	276.0	24.0	300.0
1973	1.4	125.2	179.0	190.4	112.6	30.3	6.8	3.8	2.3	0.8	0.3	0.4	608.5	44.8	653.3
1974	3.2	42.6	125.6	14.8	17.6	6.4	3.6	1.5	1.2	0.9	0.4	0.4	203.9	14.5	218.4
1975	5.6	101.5	220.2	98.9	57.9	16.3	5.7	3.2	2.2	1.2	0.6	0.4	484.0	29.5	513.6
1976	1.8	79.4	191.9	92.9	9.9	4.6	2.8	1.3	0.8	0.7	0.3	0.4	375.8	11.0	386.8
1977	23.8	115.9	170.2	110.9	28.1	9.0	5.1	2.2	2.6	2.3	0.4	0.4	448.8	22.0	470.9
1978	13.1	82.0	222.7	84.1	18.5	8.8	6.0	2.8	2.9	0.7	0.3	0.4	420.4	21.9	447.4
1979	2.5	34.0	92.3	9.8	14.4	4.0	2.9	1.1	0.8	0.7	0.3	0.4	152.9	10.2	163.2
1980	33.4	143.9	121.4	217.8	19.7	7.4	3.7	2.5	1.2	0.7	0.7	0.4	536.2	16.8	552.9
1981	4.3	62.9	133.0	76.0	27.4	7.3	4.0	2.9	3.1	3.2	0.3	0.4	303.5	21.2	324.7
1982	3.7	30.5	170.4	56.2	18.8	7.8	3.8	1.8	2.5	1.0	0.3	0.5	279.8	17.8	297.6

MONTHLY FLOWS AT KANTAMAL IN MM (1972-82)

1972	1.3	114.9	78.6	161.6	17.1	9.1	7.2	2.4	0.9	0.5	0.1	0.0	373.5	20.4	393.9
1973	2.4	261.5	131.6	90.5	61.4	37.2	7.2	2.6	1.1	0.4	0.1	0.1	547.2	48.8	596.0
1974	7.7	14.5	43.1	16.2	11.4	3.1	2.2	0.4	0.3	0.1	0.0	0.0	92.9	6.1	98.9
1975	9.3	67.4	136.1	79.4	29.9	17.2	6.4	1.5	0.6	0.1	0.0	0.2	322.1	26.0	348.2
1976	0.8	126.5	288.6	135.6	9.7	5.5	3.2	1.1	0.4	0.1	0.1	1.8	561.3	12.3	573.5
1977	2.8	74.1	177.2	257.2	15.7	12.6	3.9	2.3	1.5	0.9	0.4	0.2	526.9	23.8	550.8
1978	2.9	103.5	495.4	101.8	22.8	18.4	6.1	2.3	1.3	0.4	0.1	0.0	726.4	28.7	755.1
1979	36.3	77.2	141.0	14.7	28.5	4.0	2.2	1.2	0.3	0.1	0.1	0.0	297.6	7.8	305.4
1980	36.6	245.8	99.9	280.6	16.9	7.9	4.5	3.2	1.3	1.4	0.6	0.4	669.8	19.4	689.2
1981	1.3	6.5	208.2	94.0	27.1	3.9	4.4	1.5	0.7	1.4	0.4	0.3	337.0	17.5	354.5
1982	5.2	39.1	160.7	70.7	6.5	4.7	2.3	0.9	1.1	0.4	0.8	0.4	282.1	10.5	292.6

APPENDIX III

MONTHLY FLOWS IN MM AT HIRAKUD 1972-1982

1972	1.8	63.6	107.5	82.0	21.1	10.4
1973	1.4	125.2	179.0	190.4	112.6	30.3
1974	3.2	42.6	125.6	14.8	17.6	6.4
1975	5.6	101.5	220.2	98.9	57.9	16.3
1976	1.8	79.4	191.9	92.9	9.9	4.6
1977	23.8	115.9	170.2	110.9	28.1	9.0
1978	13.1	82.0	222.7	84.1	18.5	8.8
1979	2.5	34.0	92.3	9.8	14.4	4.0
1980	33.4	143.9	121.4	217.8	19.7	7.4
1981	4.3	62.8	133.0	76.0	27.4	7.3
1982	3.7	30.5	170.4	56.2	18.8	7.8

DEC	JAN	FEB	MAR	APR	MAY
6.6	2.3	2.1	1.2	1.0	0.4
6.8	3.8	2.3	0.8	0.3	0.4
3.6	1.5	1.2	0.9	0.4	0.4
5.7	3.2	2.2	1.2	0.6	0.4
2.8	1.3	0.8	0.7	0.3	0.4
5.1	2.2	2.6	2.3	0.4	0.4
6.0	2.8	2.9	0.7	0.3	0.4
2.9	1.1	0.8	0.7	0.3	0.4
3.7	2.5	1.2	0.7	0.7	0.4
4.0	2.9	3.1	3.2	0.3	0.4
3.8	1.8	2.5	1.0	0.3	0.5

MEANS

8.6	80.1	157.7	94.0	31.5	10.2
4.6	2.3	2.0	1.2	0.4	0.4

STANDARD DEVIATIONS

10.6	38.0	44.5	63.5	29.7	7.4
1.5	0.8	0.8	0.8	0.2	0.0

SLOPES

-74.800	2.361	0.373	0.303	0.243	0.245
0.144	0.445	0.646	0.583	-0.023	-0.028

CORRELATION WITH PREVIOUS MONTH

-0.065	0.661	0.318	0.213	0.520	0.982
0.735	0.772	0.652	0.602	-0.081	-0.210

MONTHLY FLOWS AT KANTAMAL IN MM (1972-82)

1972	1.3	114.9	78.6	161.6	17.1	9.1
1973	2.4	261.5	131.6	90.5	61.4	37.2
1974	7.7	14.5	43.1	16.2	11.4	3.1
1975	9.3	67.4	136.1	79.4	29.9	17.2
1976	0.8	126.5	288.6	135.6	9.7	5.5
1977	2.8	74.1	177.2	257.2	15.7	12.6
1978	2.9	103.5	495.4	101.8	22.8	18.4
1979	36.3	77.2	141.0	14.7	28.5	4.0
1980	36.6	245.8	89.9	280.6	16.9	7.9
1981	1.3	6.5	208.2	94.0	27.1	8.9
1982	5.2	39.1	160.7	70.7	6.5	4.7

DEC	JAN	FEB	MAR	APR	MAY
7.2	2.4	0.9	0.5	0.1	0.0
7.2	2.6	1.1	0.4	0.2	0.1
2.2	0.4	0.3	0.1	0.0	0.0
6.4	1.5	0.6	0.1	0.0	0.2
3.2	1.1	0.4	0.1	0.1	1.8
5.9	2.3	1.5	0.9	0.4	0.2
6.1	2.3	1.3	0.4	0.1	0.0
2.2	1.2	0.6	0.1	0.1	0.0
4.5	3.2	1.3	1.4	0.6	0.4
4.4	1.5	0.7	1.4	0.4	0.3
2.3	0.9	1.1	0.4	0.8	0.4

MEANS

9.7	102.8	177.3	118.4	22.5	11.7
4.7	1.8	0.9	0.5	0.2	0.7

STANDARD DEVIATIONS

13.5	83.8	124.6	86.2	15.1	9.9
2.0	0.9	0.4	0.5	0.3	0.5

SLOPES

-8.593	1.741	-0.082	-0.009	-0.034	0.568
0.149	0.312	0.376	0.624	0.330	0.163

CORRELATION WITH PREVIOUS MONTH

-0.336	0.281	-0.055	-0.013	-0.194	0.867
0.742	0.728	0.745	0.542	0.614	0.084

CROSS CORRELATION BETWEEN SITES

0.425	0.742	0.627	0.699	0.893	0.935
0.923	0.591	0.579	0.606	-0.070	0.058

SIGMA(11) =

0.909	0.386
0.386	0.909

SIGMA(22) =
0.909 0.674
0.674 0.909

SIGMA(12) =
0.601 0.085
0.326 0.255

B11 = 0.758 B12 = -0.228 B21 = 0.292 B22 = 0.156

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.474 0.774 0.486

SIGMA(11) =
0.909 0.674
0.674 0.909

SIGMA(22) =
0.909 0.570
0.570 0.909

SIGMA(12) =
0.289 0.047
0.012 -0.050

B11 = 0.621 B12 = -0.409 B21 = 0.121 B22 = -0.145

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.749 0.900 0.542

SIGMA(11) =
0.909 0.570
0.570 0.909

SIGMA(22) =
0.909 0.635
0.635 0.909

SIGMA(12) =
0.193 -0.043
0.005 -0.012

B11 = 0.399 B12 = -0.298 B21 = 0.023 B22 = -0.028

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.819 0.909 0.629

SIGMA(11) =
0.909 0.635
0.635 0.909

SIGMA(22) =
0.909 0.812
0.812 0.909

SIGMA(12) =
0.472 -0.085
0.375 -0.176

B11 = 1.142 B12 -0.891 B21 = 1.070 B22 = -0.941

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.295 0.342 0.227

SIGMA(11) =

0.909	0.812
0.812	0.909

SIGMA(22) =

0.909	0.850
0.850	0.909

SIGMA(12) =

0.893	0.772
0.830	0.788

B11 = 1.105 B12 = -0.137 B21 = 0.686 B22 = 0.254

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.029 0.139 0.042

SIGMA(11) =

0.909	0.850
0.850	0.909

SIGMA(22) =

0.909	0.839
0.839	0.909

SIGMA(12) =

0.668	0.698
0.606	0.674

B11 = 0.135 B12 = 0.641 B21 = -0.214 B22 = 0.942

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.372 0.404 0.325

SIGMA(11) =

0.909	0.839
0.839	0.909

SIGMA(22) =

0.909	0.537
0.537	0.909

SIGMA(12) =

0.702	0.727
0.507	0.662

B11 = 0.228 B12 = 0.590 B21 = -0.763 B22 = 1.432

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.320 0.348 0.031

SIGMA(11) =

0.909	0.537
0.537	0.909

```
SIGMA(22) =
  0.909   0.526
  0.526   0.909

SIGMA(12) =
  0.593   0.226
  0.437   0.678

    B11 =  0.776   B12 = -0.210   B21 =  0.062   B22 =  0.709

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

        0.497      0.402      0.330

SIGMA(11) =
  0.909   0.526
  0.526   0.909

SIGMA(22) =
  0.909   0.551
  0.551   0.909

SIGMA(12) =
  0.547   0.125
  0.342   0.493

    B11 =  0.785   B12 = -0.317   B21 =  0.094   B22 =  0.488

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

        0.519      0.636      0.438

SIGMA(11) =
  0.909   0.551
  0.551   0.909

SIGMA(22) =
  0.909  -0.064
 -0.064   0.909

SIGMA(12) =
 -0.073   0.157
  0.229   0.558

    B11 = -0.293   B12 =  0.351   B21 = -0.189   B22 =  0.728

VARIANCE(1)   VARIANCE(2) AND COVARIANCE

        0.832      0.546     -0.192

SIGMA(11) =
  0.909  -0.064
 -0.064   0.909

SIGMA(22) =
  0.909   0.053
  0.053   0.909

SIGMA(12) =
 -0.191   0.629
 -0.194   0.076
```

B11 = 1.142 B12 -0.891 B21 = 1.070 B22 = -0.741

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.295 0.342 0.227

SIGMA(11) =

0.909	0.812
0.812	0.909

SIGMA(22) =

0.909	0.850
0.850	0.909

SIGMA(12) =

0.893	0.772
0.830	0.788

B11 = 1.105 B12 = -0.137 B21 = 0.686 B22 = 0.254

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.029 0.139 0.042

SIGMA(11) =

0.909	0.850
0.850	0.909

SIGMA(22) =

0.909	0.839
0.839	0.909

SIGMA(12) =

0.668	0.698
0.606	0.674

B11 = 0.135 B12 = 0.641 B21 = -0.214 B22 = 0.942

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.372 0.404 0.325

SIGMA(11) =

0.909	0.839
0.839	0.909

SIGMA(22) =

0.909	0.537
0.537	0.909

SIGMA(12) =

0.702	0.727
0.507	0.662

B11 = 0.228 B12 = 0.590 B21 = -0.763 B22 = 1.432

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.320 0.348 0.031

SIGMA(11) =

0.909	0.537
0.537	0.909

B11 = -0.163   B12 = 0.680   B21 = -0.209   B22 = 0.069

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.450   0.863   -0.030

SIGMA(11) =

0.909	0.053
0.053	0.909

SIGMA(22) =

0.909	0.386
0.386	0.909

SIGMA(12) =

-0.139	-0.064
-0.100	-0.152

B11 = -0.149   B12 = -0.061   B21 = -0.101   B22 = -0.162

VARIANCE(1) , VARIANCE(2) AND COVARIANCE

0.884   0.874   0.362

GENERATED SEQUENCE

HIRAKUD GENERATED FLOWS

Year	June	July	Aug.	Sept.	Oct.	Nov.
	31.0	170.3	238.8	179.5	38.0	13.7
	3.9	109.7	218.4	128.4	11.7	4.3
	1.0	69.1	202.4	115.6	0.0	0.0
	15.5	59.9	170.8	22.2	75.5	22.2
	36.1	142.4	206.3	32.3	0.0	4.2
	0.0	106.9	165.5	63.4	31.2	9.5
	2.4	91.2	152.7	116.3	61.6	18.3
	5.2	43.4	131.0	24.0	0.0	0.0
	2.1	96.5	228.1	114.9	20.7	6.4
	9.3	83.8	185.4	56.2	35.8	10.9
	0.0	52.8	60.3	106.3	52.7	16.6
	10.8	87.1	154.5	90.5	30.2	9.9
	0.0	34.6	154.3	54.3	68.7	17.0
	5.7	83.5	92.0	97.8	4.3	2.9
	2.4	82.9	165.4	30.0	28.1	9.3
	4.2	102.6	163.6	0.0	0.0	0.0
	21.3	123.5	180.0	31.4	26.3	10.3
	26.4	125.4	189.4	140.1	21.5	8.6

5.8	37.3	149.4	41.3	70.8	22.1
6.4	59.8	154.9	61.9	5.4	3.8
23.7	103.8	191.4	179.8	77.2	22.0
18.7	128.7	125.1	43.7	44.2	11.9
0.0	36.0	185.1	64.6	5.2	1.5
8.1	63.2	188.3	47.7	14.2	6.0
6.8	67.5	126.8	105.8	49.4	14.6
0.0	6.2	135.2	10.8	6.7	6.3
0.0	94.2	180.3	32.1	0.0	0.1
0.0	18.5	133.2	77.4	28.5	10.8
5.0	60.7	122.2	98.0	33.6	10.9
3.3	77.3	118.1	127.6	29.6	9.4
1.4	105.0	116.1	169.4	37.5	11.1
25.9	123.5	167.0	18.3	6.3	3.1
11.7	32.3	149.0	173.9	42.7	12.8
9.8	5.3	125.8	111.7	23.3	9.3
13.8	65.8	122.5	77.9	31.6	9.6
4.8	130.2	186.7	89.8	25.9	7.3
9.5	100.1	108.2	4.3	0.0	0.0
5.0	58.9	76.1	28.9	10.9	6.9
0.0	42.5	101.9	124.4	53.2	14.6
26.9	149.6	245.3	62.6	31.4	11.8
11.9	35.6	171.0	59.3	9.2	5.9
22.4	107.9	169.9	43.1	10.0	6.3
14.4	84.6	125.5	171.6	62.9	16.8
23.7	105.9	232.0	107.2	27.8	8.9
10.2	112.3	154.2	59.7	18.2	7.4
14.8	68.3	123.1	149.7	50.1	15.6
6.1	51.1	174.7	0.0	0.0	0.0
9.6	21.8	95.1	0.0	3.3	2.9
3.8	67.8	201.0	0.0	24.2	6.3
0.0	64.7	105.4	121.8	41.6	12.1
24.2	161.0	226.6	112.1	38.1	8.7
23.0	130.9	127.6	62.1	28.5	9.1
0.0	93.1	236.3	184.2	65.3	17.8
6.9	44.3	147.7	38.7	0.2	3.1
5.8	85.9	136.8	59.8	35.3	11.4
0.0	48.7	160.2	3.7	0.0	1.4
22.5	121.7	139.8	142.9	65.8	18.6
6.3	106.1	122.2	22.2	0.0	0.0
15.4	61.2	162.7	0.0	0.0	0.9
7.6	63.2	174.2	67.2	40.6	9.6
30.9	137.3	193.4	135.4	67.8	20.1
7.3	75.3	146.1	178.6	62.2	17.4
12.9	67.9	111.2	92.4	25.6	10.8
0.0	67.6	87.2	0.0	5.1	4.8
3.0	81.8	134.4	97.3	21.0	9.1
19.6	123.4	150.8	161.5	63.5	16.3
21.4	122.6	176.6	131.7	37.5	12.4
0.0	39.9	81.0	44.4	34.1	12.1

0.0	54.6	135.1	9.4	29.4	12.1
31.3	138.4	197.2	62.1	11.8	3.6
14.0	79.9	225.1	135.9	47.2	15.1
11.0	57.8	191.0	0.0	12.5	6.3
20.7	158.0	187.0	89.1	36.6	10.6
2.0	89.7	83.1	16.9	0.0	0.0
10.7	97.8	171.9	193.6	63.7	20.0
0.0	91.4	187.3	52.7	54.0	14.9
23.2	75.7	139.9	59.4	38.5	10.0
5.8	120.7	195.9	186.4	90.6	23.9
23.5	141.6	173.6	53.0	40.1	13.0
19.5	115.8	159.0	5.9	0.0	1.2
0.0	13.2	163.3	50.2	44.0	15.8
5.0	66.3	96.6	155.0	53.2	16.4
11.6	86.0	192.6	60.5	41.6	13.0
11.9	61.3	163.7	56.1	43.9	12.7
5.1	33.7	127.0	155.0	35.0	11.9
0.0	90.1	199.6	46.9	13.9	5.1
14.9	66.7	51.5	67.3	0.0	2.2
15.0	75.2	178.1	0.0	0.0	0.0
11.9	71.1	221.5	127.2	71.2	18.7
16.1	93.0	150.7	27.7	4.8	3.9
5.0	127.8	144.5	0.0	0.0	0.7
17.8	124.6	146.9	18.6	39.8	16.1
10.1	85.6	212.9	138.6	8.9	4.7
22.0	113.7	207.9	190.3	70.1	20.5
21.2	123.3	197.1	154.1	31.9	8.6
5.0	62.2	140.9	91.7	25.1	7.6
10.7	47.8	132.1	146.0	25.0	8.0
5.9	54.2	140.6	191.3	63.2	21.2
3.6	70.7	142.4	153.7	0.0	0.0
12.9	95.0	179.4	58.5	70.1	18.4

HIRAKUD GENERATED FLOWS

DEC	JAN	FEB	MAR.	APR	MAY
4.7	3.8	3.0	2.3	0.4	0.5
3.0	2.4	3.1	1.2	0.6	0.4
3.3	1.6	0.2	0.2	0.4	0.4
4.9	3.3	2.6	2.3	0.1	0.4
4.0	2.0	1.4	0.8	0.4	0.4
4.1	2.9	2.3	2.3	0.5	0.4
6.2	2.6	1.9	2.5	0.6	0.4
2.8	2.7	2.4	2.3	0.4	0.4
4.4	2.2	1.9	0.4	0.1	0.4
3.7	1.9	2.5	1.6	0.4	0.4
7.5	3.9	3.5	2.2	0.3	0.4
4.5	2.0	1.1	0.9	0.3	0.4
3.5	2.2	1.1	1.0	0.3	0.5
4.8	2.7	3.0	0.8	0.0	0.4
5.1	2.6	3.0	2.7	0.2	0.4
1.4	0.9	1.0	2.6	0.4	0.4
3.6	2.3	1.4	1.6	0.7	0.4
5.6	1.8	1.4	0.0	0.8	0.4
7.5	3.6	1.8	1.4	0.5	0.5
3.8	1.1	1.7	0.7	0.5	0.4
7.6	3.6	2.8	0.7	0.6	0.4
6.3	2.1	2.5	1.4	0.7	0.4
5.2	2.2	0.8	0.5	0.2	0.4
5.7	2.5	2.2	1.6	0.5	0.4
5.6	2.8	1.0	0.6	0.6	0.4
6.6	3.4	2.0	1.2	0.4	0.4
3.8	2.3	2.2	2.0	0.7	0.4
4.7	2.8	2.3	0.8	0.2	0.4
3.8	2.0	1.9	1.2	0.6	0.4
4.9	2.2	1.9	1.2	0.3	0.4
5.7	2.8	2.7	1.6	0.4	0.4
4.4	2.6	3.0	1.4	0.6	0.4
4.5	2.5	1.6	0.9	0.3	0.4
4.9	2.6	1.6	1.2	0.4	0.4
5.3	2.9	2.0	0.9	0.9	0.4
3.4	2.4	1.7	0.5	0.2	0.4
5.7	2.9	2.6	2.2	0.2	0.5
3.6	2.6	1.7	0.5	0.5	0.4
5.7	2.5	2.1	0.7	1.0	0.4
4.3	2.4	0.9	0.0	0.8	0.4
5.6	3.2	1.7	2.2	0.6	0.4
3.1	1.3	1.5	0.5	0.4	0.4
5.3	3.0	2.4	1.5	0.4	0.4
5.9	2.4	2.5	1.5	0.4	0.4
3.2	1.6	2.2	1.0	0.3	0.4
5.2	3.1	1.9	2.6	0.5	0.4
4.8	2.6	2.0	0.4	0.5	0.4
4.3	2.2	2.2	1.0	0.6	0.4
3.1	1.9	1.6	0.3	0.6	0.4
3.8	1.7	2.1	2.0	0.4	0.5
3.8	1.9	2.0	0.0	0.3	0.4
5.0	2.0	1.6	0.8	0.5	0.4
5.9	2.9	3.7	2.5	0.5	0.4
4.4	1.4	1.3	0.4	0.4	0.4

5.8	2.8	2.8	1.4	0.5	0.4
3.8	1.7	2.4	1.0	0.5	0.4
6.2	3.5	2.7	1.6	0.2	0.4
1.9	1.3	1.8	0.9	0.4	0.4
1.6	1.4	0.3	0.0	0.4	0.4
4.2	2.5	1.7	1.7	0.5	0.4
6.1	2.8	3.0	2.3	0.4	0.4
6.3	2.4	2.7	1.6	0.8	0.4
4.9	2.6	2.1	1.9	0.2	0.4
2.7	1.6	0.6	0.3	0.7	0.4
3.8	1.9	2.0	1.8	0.4	0.4
7.1	3.9	2.8	1.3	0.2	0.5
3.4	1.6	1.9	0.8	0.7	0.4
5.3	2.6	2.3	2.7	0.5	0.4
4.5	2.3	2.9	1.2	0.2	0.4
3.1	1.3	1.7	2.2	0.1	0.4
6.4	3.5	3.0	1.9	0.5	0.5
3.6	1.9	1.8	1.4	0.5	0.4
4.2	2.8	2.8	1.3	0.5	0.4
5.6	2.4	1.6	1.6	0.7	0.4
5.1	2.6	1.5	1.2	0.7	0.4
6.3	2.7	2.3	1.5	0.8	0.4
5.2	2.2	2.4	2.5	0.6	0.4
6.0	3.4	2.4	1.0	0.6	0.4
5.8	3.3	1.6	1.0	0.8	0.4
2.8	1.3	2.2	2.3	0.4	0.4
6.2	3.5	4.0	3.3	0.3	0.4
5.5	2.2	1.7	0.1	0.3	0.4
2.9	1.4	1.5	0.9	0.4	0.4
3.8	1.9	0.1	0.0	0.7	0.4
5.2	2.4	2.3	1.6	0.4	0.4
3.9	2.0	1.4	1.2	0.0	0.4
3.1	1.7	1.6	0.7	0.8	0.3
2.0	0.8	0.5	1.1	0.5	0.4
4.6	3.1	3.0	1.8	0.4	0.4
3.2	1.5	1.8	1.5	0.7	0.4
2.4	1.3	1.4	1.9	0.3	0.4
5.9	3.2	2.8	0.6	0.6	0.4
4.4	1.9	1.8	1.2	0.0	0.4
6.6	2.7	1.7	1.3	0.6	0.4
2.7	1.9	1.8	0.2	0.4	0.3
3.7	2.0	1.4	1.0	0.5	0.5
5.7	3.4	3.6	1.8	0.6	0.4
5.4	3.2	4.0	2.5	0.2	0.4
3.0	1.5	0.9	0.9	0.3	0.4
7.7	3.9	3.9	2.1	0.7	0.4

MEANS

	10.6	83.7	157.7	81.5	30.4	
9.7	4.6	2.4	2.0	1.3	0.5	0.4

STANDARD DEVIATIONS

	9.0	35.9	41.1	57.8	23.7	
6.4	1.4	0.7	0.8	0.7	0.2	0.0

SLOPES

	-21.844	2.542	0.507	0.213	0.242	
0.262	0.140	0.421	0.704	0.538	-0.036	-0.031

CORRELATION WITH PREVIOUS MONTH

	-0.068	0.638	0.442	0.152	0.592	
0.974	0.649	0.810	0.636	0.571	-0.132	-0.233

GENERATED FLOWS FOR KANTAMAL

MAY	JULY	AUG	SEPT	OCT	NOV
25.5	294.5	358.1	234.7	31.6	14.3
6.6	214.7	362.3	150.0	10.2	3.2
5.9	82.4	348.1	258.8	3.5	0.0
13.4	75.0	285.3	0.0	37.4	26.0
32.3	128.3	384.2	67.0	4.4	3.0
0.0	99.3	204.4	83.0	22.9	8.6
0.0	24.7	140.2	110.2	34.6	23.7
13.8	49.0	100.1	69.9	7.6	0.0
6.0	136.1	173.0	131.2	20.6	7.1
12.6	131.5	307.8	79.5	24.0	13.7
10.5	185.3	132.1	164.7	33.9	20.3

16.4	128.5	150.5	96.3	18.8	10.9
6.6	0.0	198.8	0.0	36.5	15.6
21.1	149.3	146.1	155.9	12.1	2.5
0.0	134.2	106.8	0.0	19.6	13.8
6.7	199.4	361.4	67.7	6.0	0.0
10.0	114.5	140.5	0.0	18.5	14.5
0.0	152.5	250.2	160.1	23.1	20.8
12.3	0.0	164.4	0.0	34.9	28.5
11.5	38.1	316.3	82.6	7.3	0.0
5.0	88.3	168.6	169.2	41.0	27.6
12.7	217.5	112.6	74.9	18.7	13.8
0.0	20.6	335.5	133.9	14.0	4.2
7.5	0.0	116.0	75.4	21.1	10.1
11.1	61.3	122.4	99.6	25.7	10.4
0.0	0.0	351.8	69.4	8.9	9.8
21.9	160.8	223.3	70.2	10.5	1.6
0.0	71.4	108.0	76.8	22.0	15.9
15.4	98.4	59.4	143.0	26.7	10.4
0.0	170.2	111.9	163.8	26.1	16.0
5.9	119.7	153.6	260.1	22.2	11.4
0.4	142.6	209.6	75.2	22.1	5.4
0.0	0.0	263.7	261.7	23.9	15.0
30.7	0.0	260.1	162.4	25.5	12.0
39.0	153.5	211.2	148.0	25.5	13.7
0.0	103.3	201.4	69.3	24.4	8.8
0.0	190.2	109.3	71.2	8.9	0.0
15.5	99.9	0.0	71.0	3.5	8.1
10.0	134.8	0.0	93.2	31.2	13.8
27.8	214.7	190.9	82.1	26.4	13.1
34.8	88.9	322.7	145.7	14.4	7.2
8.0	79.8	212.1	69.7	0.0	1.2
21.3	102.3	34.1	164.3	28.7	18.4
5.2	92.0	229.5	63.2	33.7	11.9
15.2	219.1	300.0	73.0	17.4	9.1
13.3	69.6	40.2	168.5	33.3	19.6
11.9	16.3	228.7	0.0	20.1	0.0
30.2	0.0	123.7	80.6	13.3	7.1
0.0	122.5	196.1	0.0	24.8	4.7
0.0	19.3	171.3	165.6	30.2	13.0
26.9	300.4	207.3	71.9	29.6	6.9
26.4	239.1	106.5	53.6	28.1	12.4
0.0	120.9	392.1	158.9	35.9	18.0
4.0	0.0	118.4	69.4	4,8	1.4
21.2	153.1	206.5	157.6	25.1	12.7
11.1	110.5	218.7	86.1	7.5	0.0
26.2	216.3	0.0	80.4	39.5	23.3
23.0	149.9	119.3	68.2	0.0	0.0
13.4	72.5	381.3	76.2	10.4	0.0
26.1	29.1	217.8	46.4	38.7	10.3
29.4	165.9	181.5	178.3	23.3	24.2
10.7	96.6	0.0	171.1	36.1	14.5
37.1	138.0	33.0	122.9	8.2	9.9
0.0	34.1	0.0	92.8	7.0	4.8

6.2	121.7	127.9	129.8	3.5	4.7
12.0	166.2	128.4	168.4	35.9	20.3
9.8	102.6	164.4	183.4	18.9	9.7
8.9	72.9	0.0	39.8	28.4	14.9
6.3	60.0	95.3	85.5	23.7	10.7
29.6	162.8	102.7	72.5	16.7	0.9
20.9	21.3	243.4	64.7	38.4	23.3
0.0	49.6	330.3	96.5	2.8	4.1
10.8	164.0	234.7	176.0	14.0	9.9
0.0	154.8	0.0	70.7	6.2	1.2
8.0	160.0	145.7	149.5	38.2	22.3
0.0	120.1	297.5	31.8	38.4	21.3
6.4	0.0	137.0	45.6	38.4	14.1
0.0	124.4	166.7	168.1	40.3	26.3
26.6	262.3	339.9	85.9	30.5	24.2
12.1	150.5	96.1	106.7	0.0	0.0
23.7	0.0	308.3	84.5	31.7	23.3
17.1	176.0	12.1	165.9	29.9	21.4
0.0	75.4	303.8	39.6	31.5	16.9
0.0	0.0	152.1	26.8	36.0	13.4
14.4	48.7	265.6	138.2	31.1	18.7
13.2	221.9	168.6	74.4	19.8	8.3
13.3	68.9	0.0	191.4	0.0	0.8
21.8	64.5	405.8	110.2	0.0	0.0
0.2	10.4	241.0	45.2	52.5	23.2
13.4	122.1	101.2	74.6	17.8	6.4
0.0	108.4	140.2	100.6	0.2	2.1
13.1	306.2	299.7	16.7	25.2	23.3
0.0	117.3	358.1	203.9	6.8	0.0
26.0	192.6	228.1	163.3	30.4	23.1
10.2	123.9	173.4	160.5	25.8	10.7
16.8	156.0	59.2	120.6	16.4	7.3
32.4	81.2	0.0	162.0	23.9	13.1
2.0	40.4	0.0	163.7	24.1	18.7
0.0	138.6	19.4	212.2	0.0	2.4
19.7	111.7	120.2	15.0	32.5	21.3

KANTAMAL GENERATED FLOWS

DEC	JAN	FEB	MAR	APR	MAY
5.4	2.7	1.0	1.5	0.8	0.4
2.1	1.3	0.8	0.4	0.1	0.6
3.1	1.6	0.2	0.1	0.0	0.3
5.9	2.1	0.7	1.0	0.6	0.7
3.2	0.6	0.3	0.0	0.0	0.7
4.7	1.8	0.5	0.6	0.2	0.3
5.8	2.0	0.8	1.4	0.4	0.0
3.2	2.2	1.0	0.8	0.3	0.1
4.1	1.5	0.7	0.0	0.0	0.0

4.1	2.3	1.5	1.1	0.5	0.7
8.7	2.7	1.4	1.5	0.6	0.0
4.3	1.3	0.5	0.8	0.5	0.1
4.3	1.4	0.6	0.5	0.3	0.0
5.4	2.4	1.2	0.1	0.1	0.6
5.1	1.5	0.9	0.8	0.2	0.8
0.2	0.0	0.0	1.1	0.1	0.6
4.4	2.1	0.6	0.6	0.0	0.1
7.9	2.8	1.5	0.4	0.4	0.5
8.9	3.4	1.3	1.3	0.8	0.3
3.1	1.6	1.1	0.7	0.3	0.6
8.0	1.8	1.0	0.5	0.1	0.0
5.8	2.1	1.4	1.0	0.5	0.4
4.5	1.7	0.8	0.2	0.3	0.5
5.5	1.8	0.9	0.9	0.2	0.0
5.1	1.7	0.2	0.2	0.7	1.1
7.7	2.1	0.9	1.0	0.3	0.7
4.3	1.6	0.8	0.7	0.4	1.1
5.7	2.7	1.1	0.4	0.1	0.1
3.5	0.7	0.7	0.0	0.1	0.4
5.2	1.6	1.0	0.5	0.1	0.6
5.5	1.4	0.7	0.1	0.4	0.0
6.4	3.5	1.5	1.2	0.4	0.6
4.5	1.8	0.7	0.2	0.2	0.3
4.8	1.8	0.5	0.3	0.2	0.7
7.3	3.4	1.7	0.9	0.1	0.2
2.7	0.6	0.3	0.0	0.0	0.7
6.6	1.7	1.0	1.1	0.7	0.9
3.4	0.9	0.4	0.0	0.5	0.6
5.7	2.3	1.4	0.7	0.4	0.0
4.2	1.7	0.3	0.0	0.0	0.0
6.4	2.4	1.0	1.5	0.4	0.0
1.9	1.4	0.6	0.1	0.0	0.6
6.4	2.1	0.9	0.5	0.2	0.0
5.7	1.4	1.0	0.6	0.2	0.0
2.5	0.2	0.6	0.2	0.0	0.1
6.2	2.8	1.0	1.5	0.3	0.6
5.3	1.6	0.6	0.3	0.1	0.6
4.1	0.8	0.9	0.4	0.1	0.5
2.2	0.9	0.6	0.1	0.3	0.3
3.9	1.6	0.9	1.1	0.6	0.7
4.0	2.2	1.3	0.1	0.2	0.2
6.8	3.6	1.4	0.7	0.0	0.6
6.5	1.4	1.3	0.9	0.3	0.0
4.8	2.7	1.1	0.3	0.4	0.7
6.6	2.9	1.7	1.4	0.5	0.6
4.0	1.7	0.9	0.2	0.1	0.0
7.1	2.5	1.4	0.6	0.5	1.7
1.9	0.5	0.6	0.0	0.0	0.6
2.1	1.0	0.1	0.0	0.2	1.6
4.0	2.0	0.8	0.7	0.1	0.0

6.5	1.3	0.9	1.3	0.6	0.7
5.7	1.2	0.8	0.8	0.0	0.5
5.3	1.5	0.7	0.9	0.5	0.1
2.7	2.3	0.6	0.0	0.1	0.5
1.9	0.4	0.5	0.6	0.0	0.1
8.3	2.9	1.4	0.9	0.6	0.8
3.2	2.0	1.1	0.8	0.5	0.4
5.1	1.6	1.0	1.4	0.4	0.7
5.3	1.2	0.3	0.0	0.0	0.7
1.1	0.1	0.4	0.4	0.3	0.9
9.0	4.2	1.9	1.4	0.8	0.0
2.0	0.5	0.6	0.4	0.3	0.0
4.8	2.0	1.3	0.6	0.3	0.1
4.3	2.0	0.8	0.7	0.2	0.5
5.3	1.3	0.6	0.6	0.1	0.0
7.5	2.3	1.1	0.9	0.1	0.0
5.0	0.5	0.4	0.5	0.0	0.0
6.2	2.5	1.2	0.5	0.2	0.7
7.7	2.5	1.1	0.6	0.4	0.5
1.9	0.0	0.3	0.5	0.2	0.7
6.6	2.2	1.6	1.2	0.5	0.7
5.5	1.9	0.8	0.0	0.0	0.6
2.3	1.7	0.8	0.5	0.0	0.0
3.9	1.9	0.3	0.3	0.1	0.5
5.9	0.9	0.3	0.3	0.5	0.1
4.4	2.2	0.9	1.0	0.4	1.1
3.2	2.2	0.9	0.0	0.0	0.5
1.8	1.2	0.3	0.7	0.6	0.0
5.6	2.2	1.2	1.2	0.4	0.6
3.2	0.4	0.3	0.4	0.2	0.2
1.6	0.1	0.4	0.4	0.2	0.6
5.4	2.1	1.5	0.7	0.3	0.0
3.3	0.9	0.5	0.1	0.1	1.0
7.6	2.2	0.3	0.0	0.0	0.8
3.9	1.4	1.0	0.0	0.0	0.0
2.9	2.3	1.1	1.4	0.8	0.7
6.1	2.0	1.1	0.3	0.0	0.0
5.9	2.1	1.6	0.9	0.2	0.4
2.5	1.9	0.3	0.0	0.1	0.8
8.9	2.7	1.3	0.8	0.3	0.6

4.1	2.3	1.5	1.1	0.5	0.7
8.7	2.7	1.4	1.5	0.6	0.0
4.3	1.3	0.5	0.8	0.5	0.1
4.3	1.4	0.6	0.5	0.3	0.0
5.4	2.4	1.2	0.1	0.1	0.6
5.1	1.5	0.9	0.8	0.2	0.8
0.2	0.0	0.0	1.1	0.1	0.6
4.4	2.1	0.6	0.6	0.0	0.1
7.9	2.8	1.5	0.4	0.4	0.5
8.9	3.4	1.3	1.3	0.8	0.3
3.1	1.6	1.1	0.7	0.3	0.6
8.0	1.8	1.0	0.5	0.1	0.0
5.8	2.1	1.4	1.0	0.5	0.4
4.5	1.7	0.8	0.2	0.3	0.5
5.5	1.8	0.9	0.9	0.2	0.0
5.1	1.7	0.2	0.2	0.7	1.1
7.7	2.1	0.9	1.0	0.3	0.7
4.3	1.6	0.8	0.7	0.4	1.1
5.7	2.7	1.1	0.4	0.1	0.1
3.5	0.7	0.7	0.0	0.1	0.4
5.2	1.6	1.0	0.5	0.1	0.6
5.5	1.4	0.7	0.1	0.4	0.0
6.4	3.5	1.5	1.2	0.4	0.6
4.5	1.8	0.7	0.2	0.2	0.3
4.8	1.8	0.5	0.3	0.2	0.7
7.3	3.4	1.7	0.9	0.1	0.2
2.7	0.6	0.3	0.0	0.0	0.7
6.6	1.7	1.0	1.1	0.7	0.9
3.4	0.9	0.4	0.0	0.5	0.6
5.7	2.3	1.4	0.7	0.4	0.0
4.2	1.7	0.3	0.0	0.0	0.0
6.4	2.4	1.0	1.5	0.4	0.0
1.9	1.4	0.6	0.1	0.0	0.6
6.4	2.1	0.9	0.5	0.2	0.0
5.7	1.4	1.0	0.6	0.2	0.0
2.5	0.2	0.6	0.2	0.0	0.1
6.2	2.8	1.0	1.5	0.3	0.6
5.3	1.6	0.6	0.3	0.1	0.6
4.1	0.8	0.9	0.4	0.1	0.5
2.2	0.9	0.6	0.1	0.3	0.3
3.9	1.6	0.9	1.1	0.6	0.7
4.0	2.2	1.3	0.1	0.2	0.2
6.8	3.6	1.4	0.7	0.0	0.6
6.5	1.4	1.3	0.9	0.3	0.0
4.8	2.7	1.1	0.3	0.4	0.7
6.6	2.9	1.7	1.4	0.5	0.6
4.0	1.7	0.9	0.2	0.1	0.0
7.1	2.5	1.4	0.6	0.5	1.7
1.9	0.5	0.6	0.0	0.0	0.6
2.1	1.0	0.1	0.0	0.2	1.6
4.0	2.0	0.8	0.7	0.1	0.0

6.5	1.3	0.9	1.3	0.6	0.7
5.7	1.2	0.8	0.8	0.0	0.5
5.3	1.5	0.7	0.9	0.5	0.1
2.7	2.3	0.6	0.0	0.1	0.5
1.9	0.4	0.5	0.6	0.0	0.1
8.3	2.2	1.4	0.9	0.6	0.8
3.2	2.0	1.1	0.8	0.5	0.4
5.1	1.6	1.0	1.4	0.4	0.7
5.3	1.2	0.3	0.0	0.0	0.7
1.1	0.1	0.4	0.4	0.3	0.9
9.0	4.2	1.9	1.4	0.8	0.0
2.0	0.5	0.6	0.4	0.3	0.0
4.8	2.0	1.3	0.6	0.3	0.1
4.3	2.0	0.8	0.7	0.2	0.5
5.3	1.3	0.6	0.6	0.1	0.0
7.5	2.3	1.1	0.9	0.1	0.0
5.0	0.5	0.4	0.5	0.0	0.0
6.2	2.5	1.2	0.5	0.2	0.7
7.7	2.5	1.1	0.6	0.4	0.5
1.9	0.0	0.3	0.5	0.2	0.7
6.6	2.2	1.6	1.2	0.5	0.7
5.5	1.9	0.8	0.0	0.0	0.6
2.3	1.7	0.8	0.5	0.0	0.0
3.9	1.9	0.3	0.3	0.1	0.5
5.9	0.9	0.3	0.3	0.5	0.1
4.4	2.2	0.9	1.0	0.4	1.1
3.2	2.2	0.9	0.0	0.0	0.5
1.8	1.2	0.3	0.7	0.6	0.0
5.6	2.2	1.2	1.2	0.4	0.6
3.2	0.4	0.3	0.4	0.2	0.2
1.6	0.1	0.4	0.4	0.2	0.6
5.4	2.1	1.5	0.7	0.3	0.0
3.3	0.9	0.5	0.1	0.1	1.0
7.6	2.2	0.3	0.0	0.0	0.8
3.9	1.4	1.0	0.0	0.0	0.0
2.9	2.3	1.1	1.4	0.8	0.7
6.1	2.0	1.1	0.3	0.0	0.0
5.9	2.1	1.6	0.9	0.2	0.4
2.5	1.9	0.3	0.0	0.1	0.8
8.9	2.7	1.3	0.8	0.3	0.6

MEANS

12.0	110.8	179.5	105.9	21.5	11.4	
4.8	1.8	0.9	0.6	0.3	0.4	

STANDARD DEVIATIONS

10.5	73.1	110.4	61.4	12.2	8.1	
1.9	0.8	0.4	0.5	0.2	0.4	

SLOPES

6.414	1.891	0.026	-0.014	-0.015		
0.554	0.174	0.302	0.372	0.581	0.315	0.286

CORRELATION WITH PREVIOUS MONTH

0.224	0.273	0.018	-0.025	-0.075	0.836
0.730	0.708	0.743	0.530	0.645	0.171

CROSS CORRELATION BETWEEN SITES

0.431	0.723	0.608	0.701	0.855	0.927
0.915	0.560	0.622	0.661	-0.063	0.378