Plant Archives Vol. 18 No. 1, 2018 pp. 325-330 ***ISSN 0972-5210***

PERFORMANCE OF THOMAS FIERING MODEL FOR GENERATING SYNTHETIC STREAMFLOW OF JAKHAM RIVER

Priyanka Sharma[1], S. R. Bhakar[2] and P. K. Singh[2]

[1]Department of Soil Sciences and Agricultural Chemistry, Lovely Professional University, Phagwara (Punjab), India.
[2]Department of Soil and Water Engineering, CTAE Udaipur - 313 001 (Rajasthan), India.

Abstract

This study analyzed the monthly (June to May) streamflow data series of Jakham river for evaluating the performance of Thomas Fiering model for generating synthetic streamflow. In this study, 40 years (1975 to 2015) of streamflow data has been used in which 1975-2005 (360 months) were used to build the model and used them to predicting the Inflow data for the period 2005-2015 (120 months). The statistical performance evaluation parameters *i.e.* R and RMSE of Thomas Fiering model between observed and predicted data in the validation period has been calculated. The results showed that Thomas Fiering model is considered as satisfactory with R and RMSE values i.e. 0.731 and 28.470, respectively, for generating synthetic monthly streamflow of Jakham river. A significant relationship between the predicted and actual (observed) monthly inflow time series has been shown for Jakham river. The value of coefficient of determination (R^2) is 0.534, which is slightly less for both modeled and observed time series but within the acceptable range, This indicate that Thomas Fiering model performed well and It can be concluded that Thomas-Fiering model was suitable for generating synthetic monthly streamflow of Jakham river, needed for water resources planning.

Key words: Streamflow, Thomas Fiering model, performance analysis and Jakham river.

Introduction

Stochastic simulation of hydrologic time series has been widely used for solving various problems associated with the planning and management of water resources systems for several decades (Kim *et al*., 2004). Stochastic monthly streamflow models are often used in simulation studies to evaluate the likely future performance of water resource systems (Stedinger *et al*., 1982). Synthetically generated flows have many uses to the water resources planner. They are of equal importance as historic flows in simulation and optimization schemes used to study several feasible alternatives of planning, design and operation of water resources projects (Wijayaratne and Chan, 1987).

The role of stochastic methods in water resources was first explored by Thomas and Fiering (1962) in the context of system design and operational studies through the generation of synthetic sequences of streamflow through Monte Carlo simulation. They developed a stochastic data generation model incorporating the serial correlation behaviour of hydrologic data. This serial correlation model was an example of Markovian type models; that is a lag-one Markov model.

For the first type of models, the Thomas Fiering (TF) model can be regarded as a typical stochastic approach for forecasting in hydrology (Harms and Campbell, 1967; Joshi and Gupta, 2009; McMahon and Miller, 1971; Thomas and Fiering, 1962). Harms and Campbell (1967) extended the TF model to preserve the normal distribution of annual flows, the lognormal distribution of monthly flows, and the autocorrelation of both annual and monthly flows. Modelers later disaggregated the annual flow requirement, usually data from a terminal reservoir, into the monthly flow requirements by establishing the correlation between annual and monthly flows (Kurunç *et al*., 2005). Recent researchers have included the TF model as part of a simulation model for the operation of reservoir system (Joshi and Gupta, 2009).

The generated data sequences, particularly monthly time series such as streamflow or rainfall are widely used in water resources planning and management to understand the variability of future system performance.

Stochastic data generation aimed at generating synthetic data sequences that are statistically similar to the observed data sequences. Therefore, the generated data is important for more accurate solutions of various complex planning, design and operational problems in water resources development.

Materials and Methods

Study area

The study was conducted for the Jakham river, originates in the hills of south-west of Chotti Sadari of Chittorrgarh district, Rajasthan, India. At present on river Jakham, which is a tributary of river Mahi, one masonary gravity dam 81 m high is constructed near village Anooppura of district Pratapgarh. The latitude of the dam site is 24^0-10'-30″ N and longitude 74^0-35'-30″ E. The catchment area of Jakham dam site is 1010 km^2 and it is “Fan” shaped. The average annual rainfall in the study area is about 780 mm. The average annual runoff from the Jakham river catchment is 196.0 MCM at 75 per cent probability level, of which about 142.0 MCM contributes to gross storage (live storage is 132.3 MCM and dead storage 9.7 MCM) of the reservoir.

Thomas Fiering Model for generating synthetic streamflow

The monthly flow series are non-stationary and therefore complicated mathematical models are employed in their simulation. The first model that appeared in the hydrology literature for the generation of synthetic monthly flow sequences is that due to Thomas & Fiering (1962). Basically, this model is of a Markovian nature with periodic parameters, namely, the monthly means, standard deviations and the lag-zero crosscorrelations between successive months. The first order Markov model assumes that the process is stationary in its first three moments. It is possible to generalize the model so that the periodicity in hydrologic data is accounted for to some extent. The main application of this generalization has been in generating monthly streamflow where pronounced seasonality in the monthly flows exists.

Monthly streamflow data have been generated by using Thomas-Fiering model. Initially a known streamflow of any month (say, December) along with the mean and standard deviation of historical streamflow for that month were fed to Eq. 1. The output produced by this Eq. is the streamflow of the succeeding month.

In present study, total data from 1975-76 to 2014-15 (480 sets) were adopted for develop and validate the Thomas Fiering model for Jakham river. Out of the 480 data set 75 per cent (360 sets) were adopted for developing and remaining 25 per cent (120 sets) for validation of model. Fig. 1 shows a regression analysis of q_{j+1} on q_j, pairs of successive monthly flows for the months (j+1) and j over the years of record where j = 1, 2, 3, ..., 12 (Jan, Feb, ... Dec) and when j = 12, j+1 = 1 = Jan (there would be 12 such regressions). If the regression coefficient of month j+1 on j is b_j, then the regression line values of a monthly flow, q_{j+1}, can be determined from the previous months flow q_j, by the Eq.

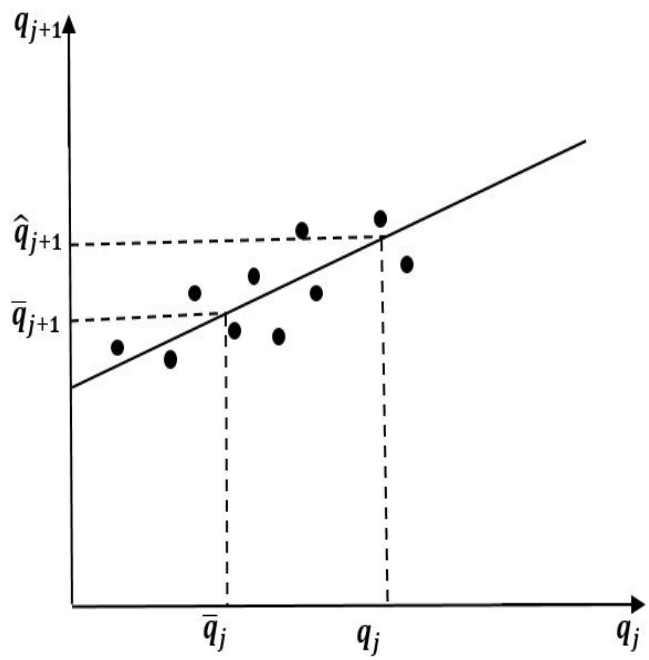

Fig. 1 : Thomas-Fiering model.

The model assumes that the entire influence of the past on the current flow is reflected in the previous flow value. In its simplest form the model consists of twelve regression Eq.s, one for each month. The model implicitly allows for the non-stationarity observed in monthly flow data. The Thomas–Fiering model Eq. is given by

$$Y = \bar{Y} + r \frac{S}{S_j}(Y - \bar{Y}) + US\,ul - r \quad (1)$$

Where,

Y_{i+1} = value to be simulated for i+1 month from i^{th} month.

Y_i = last observed value for the month i.

$\bar{Y}$ & $\bar{Y}$ = mean monthly values during the j+1 and j^{th} month, respectively.

$r_{j,j+1}$ = serial correlation coefficient between values in j^{th} and j+1 month.

S_j, S_{j+1} = standard deviations of monthly values during j, j+1 months, respectively.

U_i = random normal deviate with zero mean and unit variance.

The statistical performance evaluation indices of Thomas Fiering model to generate the synthetic streamflow was compared with observed monthly inflow during validation period using coefficient of correlation (R), Root mean square error (RMSE).

Results and Discussion

The Thomas Fiering model was developed for generating synthetic streamflow of Jakham river using MS excel. Statistical parameters *i.e.* mean, standard deviation, lag 1 serial correlation coefficient, regression coefficient for the period of 360 months used for generating streamflow of Jakham river through Thomas Fiering model. These statistical parameters can be calculated using Microsoft Excel or excel based software. The result of statistical parameters of observed inflow series is shown in table 1.

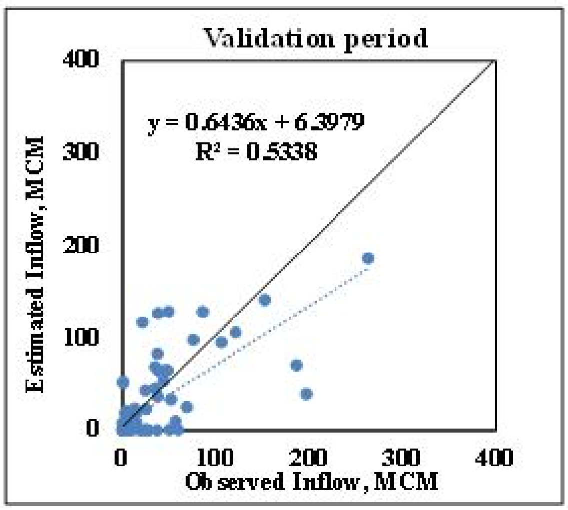

Fig. 2 : Scatter plot of monthly observed and fitted inflow by Thomas Fiering model during validation period.

Statistical performance indices of Thomas Fiering model during validation period

The statistical performance evaluation parameters i.e. R, RMSE, MNSE and MIA of Thomas Fiering model between observed and predicted data in the validation period (2005-06 to 2014-15) has been calculated. The results are presented in table 2. From table 2, it is observed that coefficient of correlation is 0.731, which is acceptable range of R to fit the model and generate synthetic streamflow. The value of R approaching to 1 indicates the best fit model for prediction. The minimum RMSE value (28.470) indicates the model performed well. Further, the values of MNSE and MIA of Thomas Fiering model were calculated and are presented in table 2. From the table 2, it is observed that the value of MNSE (0.456) and MIA (0.731) is slightly less but still within the acceptable range (Fernandez *et al.*, 2005 and Machiwal and Jha, 2015). Hence, it can be concluded that Thomas Fiering model is considered as satisfactory for generating synthetic monthly inflow of Jakham river. Scatter plot of monthly observed and fitted inflow by Thomas Fiering model is presented in fig. 2. It is observed from the fig. 2 the value of coefficient of determination (R^2) is 0.534, which is slightly less for both modeled and observed time series but within the acceptable range, This indicate that Thomas Fiering model performed well.

Table 1 : Statistical parameters for observed Inflow time series for development of Thomas Fiering Model.

Month	Mean	Standard deviation	Regression coefficient	Lag 1 Serial correlation
Jun	7.851	16.140	0.567	0.274
Jul	36.578	33.387	0.173	0.081
Aug	107.211	71.526	0.326	0.276
Sep	73.777	84.269	0.004	0.015
Oct	20.634	20.076	-0.103	-0.271
Nov	7.996	7.640	-0.029	-0.076
Dec	3.891	2.892	0.052	0.097
Jan	2.581	1.559	0.379	0.511
Feb	2.011	1.155	0.413	0.429
Mar	1.518	1.111	0.202	0.331
Apr	0.511	0.678	0.089	0.134
May	0.271	0.454	0.000	-0.098

Table 2 : Statistics of observed and calculated flow using Thomas-Fiering model.

S. no.	Statistical test	Values
1.	Correlation coefficient (R)	0.731
2.	Root Mean square error (RMSE)	28.470
3.	Modified Nash Suctlif efficiency (MNSE)	0.456
4.	Modified Index of Agreement (MIA)	0.731

Comparison between observed and generated inflow

Monthly inflow data have been generated by using Thomas-Fiering model. Initially a known inflow of any month (say, December) along with the mean and standard deviation of historical inflow for that month were fed to Eq. 1. The output produced by this equation is the inflow of the succeeding month. As shown in Eq. 1, this equation

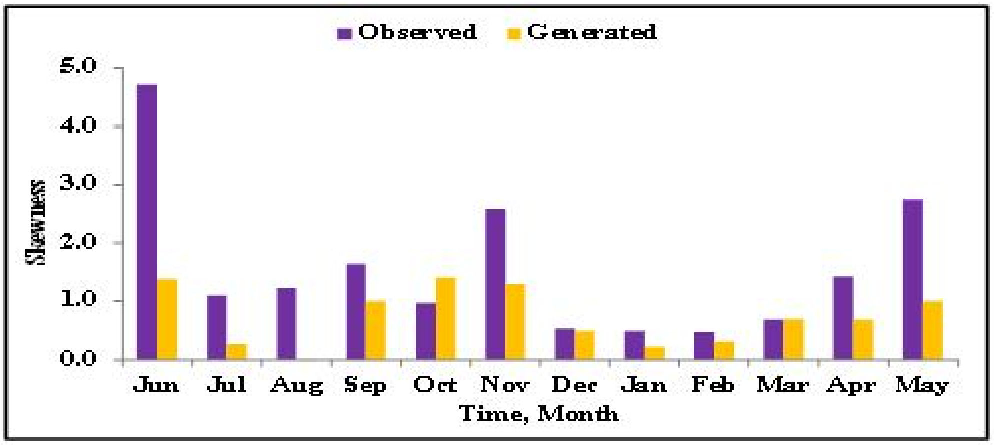

Fig. 3 : Comparison between skewness of observed and generated inflow using T-F model.

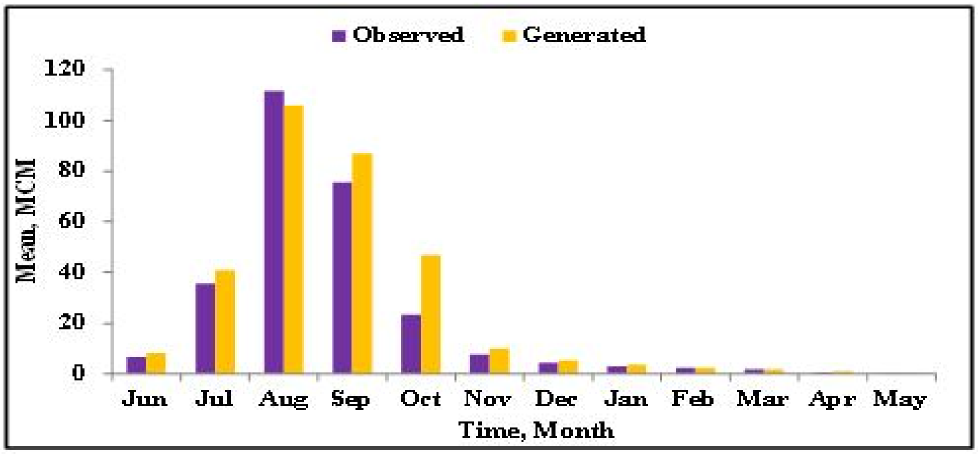

Fig. 4 : Comparison between mean monthly inflow of observed and generated inflow using T-F model.

contains a random part which has a great effect on the statistics of the generated inflow especially the skewness of the generated inflow (fig. 3).

In this study, 100 years of synthetic inflow has been generated using Thomas Fiering model. Same duration of data has been generated by (Ray and Sarma, 2016 and Ahmed and Sarma, 2007). It is worth to be mentioned that if the generated inflow became negative, then it was replaced with the minimum observed inflow of that month (Mezaache and Mansouri, 2015 and Ray and Sarma, 2016).

Statistical characteristics *viz*. mean and standard deviation between generated and observed Inflow time series of Jakham river have been analyzed. The results of comparison between mean monthly inflow and standard deviation statistics of observed and generated inflows by Thomas Fiering models is depicted on are represented in table 3 and figs. 4 and 5.

From the table 3, it is observed that the monthly mean values of the generated inflow series show that model underestimate the higher values and overestimate the lower values. This is because model generates values near the mean, which may be utilized for water resources planning. The standard deviation statistics presented in fig. 4 shows that generated and observed series are similar except in the month of August and October, it is due the uncertainty of occurrence of rainfall these months. It is depicted from fig. 5 that the Thomas Fiering model can successfully model the time series of monthly inflows and it is concluded that Thomas Fiering model is well suited for generating synthetic inflow. Thus, the Thomas-Fiering model was suitable for generating synthetic monthly inflow of Jakham river, needed for water resources planning.

Conclusion

Proper planning, efficient management and optimal operation of the water resources system is an utmost need of the recent time. The synthetic data sequences are needed in simulation studies for the design and operation of water storage, conveyance and control structures. The statistical performance evaluation parameters *i.e.* R, RMSE, MNSE and MIA of Thomas

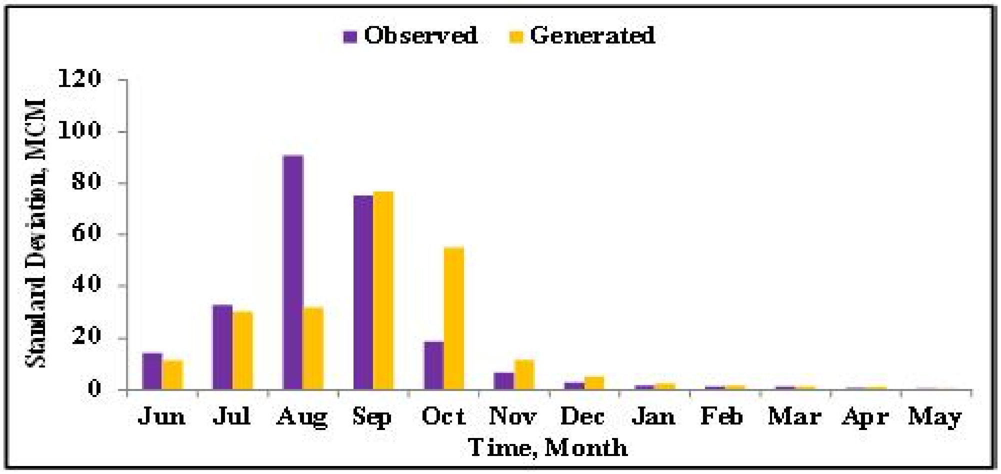

Fig. 5 : Comparison between standard deviation of observed and generated inflow using T-F model.

Table 3 : Statistics of observed and generated inflow using Thomas-Fiering model.

S. no.	Months	Observed mean values	Generated mean value	Observed standard deviation	Generated standard deviation	Observed skewness	Generated skewness
1	June	6.76	8.420	14.12	11.40	4.72	1.26
2	July	35.42	40.729	33.06	30.50	1.09	0.44
3	Aug	111.76	105.904	90.79	32.01	1.22	0.24
4	Sept	75.68	86.885	75.11	76.76	1.64	0.73
5	Oct	23.45	47.092	18.84	54.97	0.96	1.04
6	Nov	7.77	10.053	6.69	11.50	2.58	1.19
7	Dec	4.28	5.579	2.74	5.08	0.53	0.66
8	Jan	2.98	3.532	1.68	2.43	0.49	0.14
9	Feb	2.31	2.401	1.32	1.66	0.48	0.47
10	Mar	1.78	1.813	1.24	1.25	0.69	0.19
11	Apr	0.68	1.007	0.71	0.98	1.41	0.82
12	May	0.31	0.460	0.42	0.51	2.74	0.83

Fiering model between observed and predicted data in the validation period has been calculated. Results of Thomas Fiering model showed that model is performed well for generating the synthetic streamflow with R, RMSE, MNSE and MIA values *i.e.* 0.731, 28.470, 0.456 and 0.731, respectively. Hence, it can be concluded that Thomas Fiering model was suitable to simulate monthly Jakham river inflow and also able to generate a synthetic streamflow data for a required period which was similar to original data.

References

Ahmed, J. A. and A. K. Sarma (2007). Artificial neural network model for synthetic streamflow generation. *Water Resour. Manag.*, **21(6)** : 1015.

Fernandez, G. P., G. M. Chescheir, R. W. Skaggs and D. M. Amatya (2005). Development and testing of watershed-scale models for poorly drained soils. *Trans. ASAE*, **48(2)** : 639–652.

Harms, A. A. and T. H. Campbell (1967). An extension to the ThomaseFiering model for the sequential generation of streamflow. *Water Resour. Res.*, **3** : 653-661.

Joshi, G. S. and K. Gupta (2009). A simulation model for the operation of multipurpose multireservoir system for River Narmada, India. *J. Hydro-environ. Res.*, **3** : 96-108.

Kim, B. S., H. S. Kim and B. H. Seoh (2004). Streamflow simulation and skewness preservation based on the bootstrapped stochastic models. *Stochastic Environ. Res. Risk Asmt.*, **18(6)** : 386-400.

Kurunç, A., K. Yu¨rekli and O. Çevik (2005). Performance of two stochastic approaches for forecasting water quality and streamflow data from Yes,ilirmak River, Turkey. *Environ. Model. Softw.*, **20** : 1195e1200.

Machiwal, D. and M. K. Jha (2015). GIS-based water balance modeling for estimating regional specific yield and distributed recharge in data-scarce hard-rock regions. *J. Hydro Environ. Res.*, **9(4)** : 554-568.

McMahon, T. A. and A. J. Miller (1971). Application of the

Thomas and Fiering model to skewed hydrologic data. *Water Resour. Res*., **7** : 1338e1340.

Mezaache, M. and R. Mansouri (2015). Assessment of reservoir behaviour: a case study of the Bouhamdane Dam. *Int. J. Water*, **9(4)** : 376–394.

Ray, M. R. and A. K. Sarma (2016). Influence of Time Discretization and Input Parameter on the ANN Based Synthetic Streamflow Generation. *Water Resour. Manag*., **30(13)** : 4695-4711.

Stedinger, J. R. and M. R. Taylor (1982). Synthetic streamflow generation, 1. Model verification and validation. *Water Resour. Res*., **18(4)** : 909-918.

Thomas, H. A. and M. B. Fiering (1962). Mathematical synthesis of streamflow sequences for the analysis of river basins by simulation. *Design of Water Resour. Sys.*, pp.459-493.

Wijayaratne, L. H. and P. C. Chan (1987). Synthetic Flow Generation with Stochastic Models. In: Singh V. P. (eds) *Flood Hydrology.* Springer, Dordrecht. pp 175-185.