USE OF DISCHARGE AND RAINFALL DATA IN RAINFALL RUNOFF MODELLING FOR A CATCHMENT IN TANZANIA.

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ABSTRACT

Observing discharge hydrograph, it can be concluded whether rainfall has fallen in the catchment. But rainfall distribution in a catchment is usually inhomogeneous, thus it is likely that rainfall may fall at the location where there is no rain gauge (rain fall measuring device). To get a representative catchment rainfall data, there should be as many rainfall gauging stations as possible.

In this paper 6 rainfall gauging stations were used to calculate the discharge at Ihimbu station located at the outlet of the Little Ruaha catchment, Tanzania. In another scenario, three rainfall gauging site were replaced by one discharge measurement at Makalala, upstream of Ihimbu. The later case gave an improved calculation of the discharge at the outlet. Multiple input single output techniques were applied to system models and conceptual models and the results were compared. It is concluded that in order to have a relative accurate calculation of the downstream discharge, it is better to have as many as possible discharge measuring stations upstream and tributary.

1.0 INTRODUCTION

The increased catastrophic and disasters due to the adverse effect of the hydrological events calls for more understanding of the principles governing the system. If floods are well forecasted/calculated, their dangers can be brought to a minimum by providing control measures and warnings. To calculate the discharge at the forecast area (downstream) a good network of rainfall station is needed and a good transformation model has to be formulated.

Models used to transform input data series to output series (discharge) include **system models** being linear or non-linear models, and also **conceptual models** which try to consider some physical processes governing the transformation. The performance or efficiency (1) of the model is tested by using (R^2) (eq.1):

$$R^2 = \frac{(F_o - F)}{F_o} \tag{1}$$

Where F is the sum of squares of the difference between the observed and estimated discharge over the calibration period given and F_0 is the sum of square of the departure from the mean for the whole series. Some of these models were applied to Little Ruaha catchment, in Tanzania to study the use of rainfall data and discharge data in rainfall runoff modelling

2. OBJECTIVES

It is the objective of this study to explore the accuracy of different system models and conceptual models, subjected to different data input i.e whether rainfall and runoff (discharge) separately or combination of the two could improve the accuracy of the model and thus suggesting the system of gauging or data necessary for modelling of the catchment response.

3. LOCATION OF LITTLE RUAHA

Tanzania is a semi-arid country transversed on average by a line of 6° below the equator. The location of little Ruaha catchment is shown in Fig. 1. Fig. 2 shows the catchment map and data collection stations.

Outlet of the catchment is at Ihimbu Station and there is an upstream station at Makalala. The latter is about 40 km from Ihimbu. The area covered up to Makalala is 759 Km^2 and for the whole catchment is 2480 Km^2. The catchment has on average an annual historical rainfall of 1000 mm/yr. Description of the catchment and it discharge measuring stations are summarized in sheet No.1 (appendix 1). There are six rainfall gauging stations in the catchment with continuous data for 9 years (1966-1975). Discharge at Ihimbu are available from 1957 to 1979 while at Makalala are available from 1965 to 1976. The catchment has only one evaporation station at Madibira with data from 1966 to 1980. For the analysis, 9 years of concurrent data were used. Fig.3 shows the typical hydrologic diagram of the catchment as approximated from the available data by fitting a 4-harmonics seasonal model.

4. MODEL APPLICATION

A number of rainfall runoff models were applied ranging from conceptual models to system models. Conceptual models are the one built by considering some physical processes governing the transformation while system model are built by considering mathematical formulations. The system models may be linear or non-linear. The linear model assumes a linear transformation (2) of input series to output series. Non linear models combines the non linear components like quadratic terms, Meixner functions (3) etc, to transform the series. For a linear system in which the cause (eg. rainfall, X) precedes the effect (eg. runoff, Y) and in which no input or output occurs prior to time t=0, the relationship of input, output and impulse response is expressed by the convolution integral (eq.2). The integral can be discretised as shown in equation 3. Fig.4 shows a linear model with a linear component H, being a unit hydrograph.

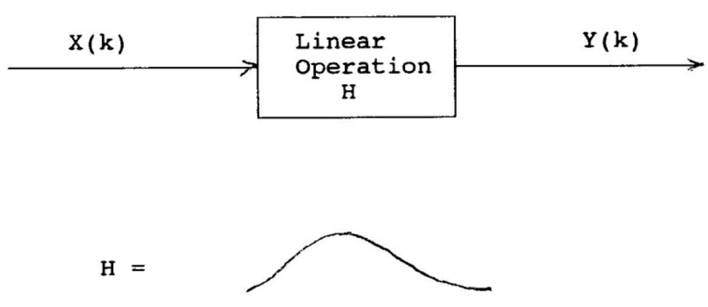
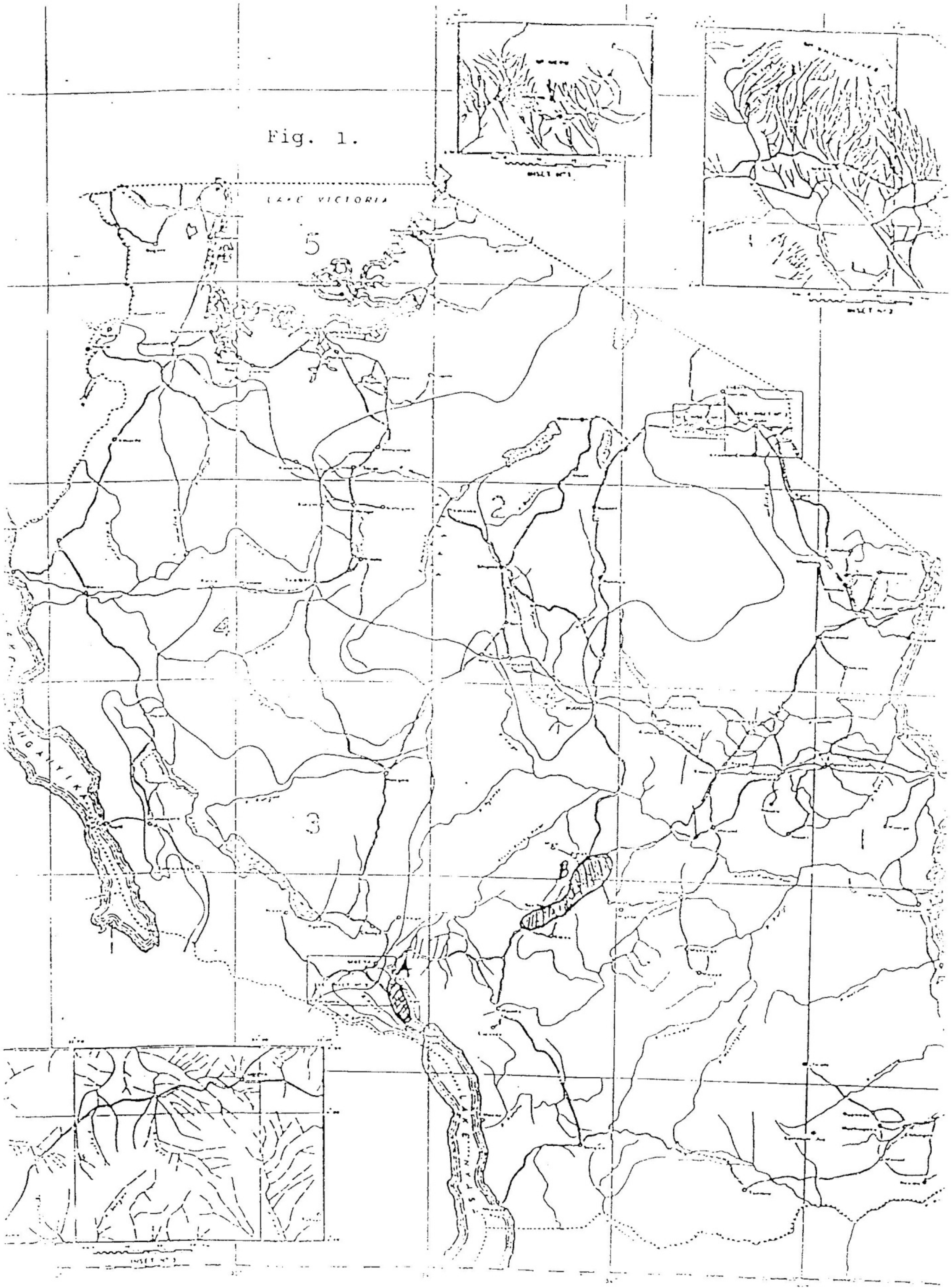


Fig.4 Representation of a linear model

Fig. 1.



1 - INDIAN OCEAN DRAINAGE AREA
2 - INTERIOR DRAINAGE (LAKES NATRON, MANYARA, EYAS ETC.)
3 - INTERIOR DRAINAGE - LAKE RUKWA
4 - ATLANTIC OCEAN DRAINAGE AREA
5 - MEDITERREAN SEA DRAINAGE AREA

A - MBAKA CATCHMENT
B - LITTLE RUAHA CATCHMENT

Compiled and Drawn by M.A. Fernandes

Water Development and irrigation department,
Project planning Station, Ubungo
Dar es Salaam, May 1960
Revised January 1961

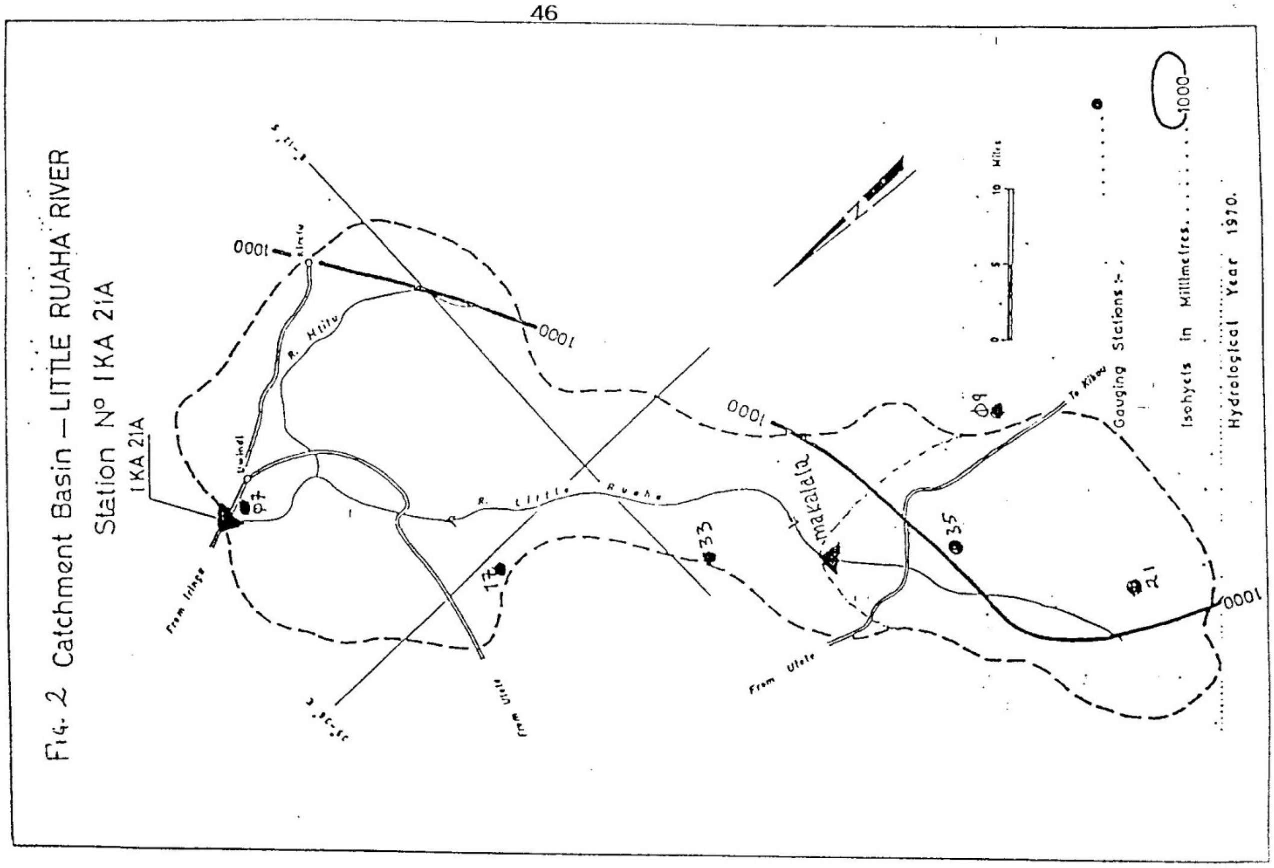
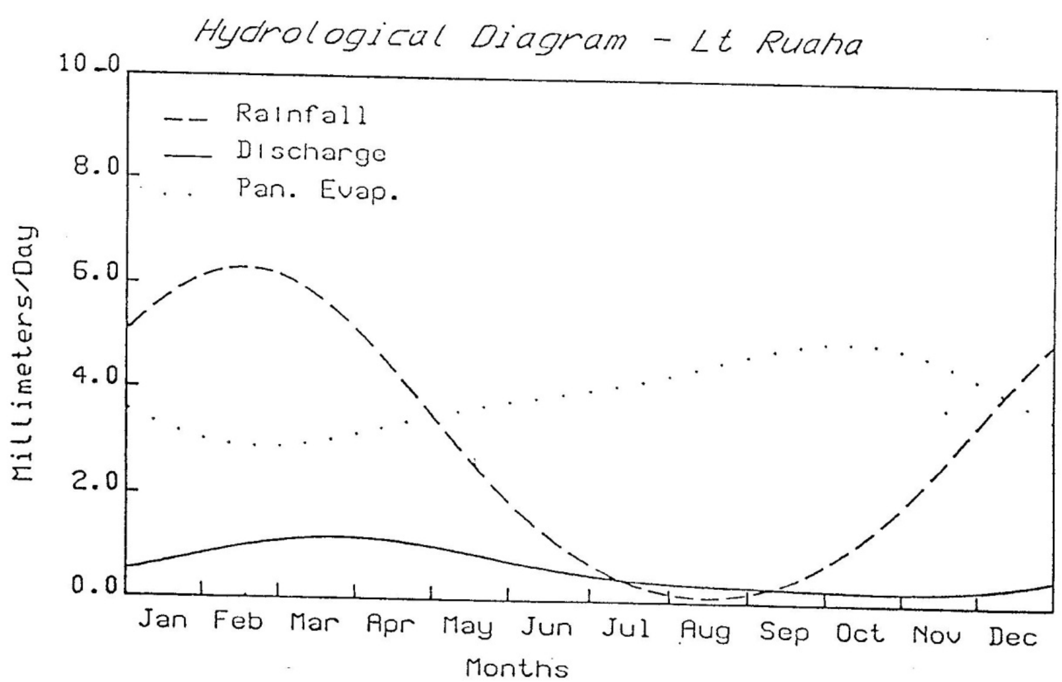


Fig. 2 Catchment Basin — LITTLE RUAHA RIVER Station No IKA 21A



Figure, 3 Seasonal mean rainfall, discharge and evaporation

Linear perturbation (1) is introduced when only the perturbations are taken as input series. The perturbations are generally departures from the seasonal means i.e the seasonality component being removed from the input series.

$$Y(t) = \int_{0}^{t} X(\tau) h(t-\tau) d\tau \tag{2}$$

Where h(t) is the unit response function
For a discretised time the above equation becomes (eq.3)

$$Y_k = \sum_{j=1}^{m} H_j X_{(k-j+1)} \tag{3}$$

Models applied are as follows (1):

1. Single Input Linear Model (Unconstrained) SILM/U
2. Single Input Linear Model (Volume constrained) SILM/V
3. Single Input Linear Model (Diff.equation with updating)
4. Seasonal Model (SM)
5. Single Input Linear Perturbation Model (Unc.) SILPM/U
6. Single Input Linear Perturbation Model (gamma) SILPM/g
7. Single Input Linear Perturbation Model (Nash) SILPM/N
8. Multiple Input Linear Model (Unco.) MILM/U
9. Multiple Input Linear Model (gamma) MILM/g
10. Multiple Input Linear Model (Nash.) MILM/N
11. Multiple input linear perturbation model (Unco.) MILPM
12. Multiple input linear perturbation model (Diff. eq.)
13. Single Input Non-linear Model (Meixner)
14. Single Input Non-linear Perturbation Model (Meixner)
15. Single Input Non-linear Perturbation Model (API)
16. Seasonal Moisture Accounting and Routing Model (SMAR)
17. Modified SMAR (Effective rainfall)
18. The Danish NAM Model
19. The Chinese XINANJIANG Model.

In all models the daily average rainfall of the catchment were applied as input to the model except the multiple input model where discharge at Makalala was used as one of the input.

For multiple input technique the rainfall station above Makalala was replaced by a single discharge station at Makalala as one input. The second input was taken to be the average rainfall of the inbetween catchment (Makalala - Ihimbu). This model assumes a simple linear relation (4) between various input X1(t), X2(t).... being upstream tributary inflows and/or the average rainfall over the intervening catchment, to the output Y(t) being the discharge at the outlet of the catchment (eq.4).

$$y_i = \sum_{j=1}^{m(1)} x_{i-j+1}^{(1)} h_j^{(1)} + \sum_{j=1}^{m(2)} x_{i-j+1}^{(2)} h_j^{(2)} + \ldots + \sum_{j=1}^{m(L)} x_{i-j+1}^{(L)} + e_i \qquad (4)$$

$h_j^{(1)}$ = jth ordinate of the pulse response relating the first input to a component of the output
m(1) = memory length of the system for the first input series
Table 1 gives the R^2 of different system approach model and
Table 2 gives the R^2 of the conceptual models.

Table 1 Summary of the system models applied

MODEL	CALIBRATION memory	CALIBRATION means (ratio)	R%	VERIFICATION means (ratio)	VERIFICATION R%
LINEAR MODELS *************					
SILM (Unconstrained)	60	1.12	71	0.88	52
SILM (Vol. Constr.)	60	1.03	53	0.82	10
SILM (Diff. eq.)	50	1.33	62	1.03	68
" Updating	50	1.05	96	1.04	93
SEASONAL MODEL **************					
Seasonal Model	-	1.0	50	0.87	59
LINEAR PERTUBATION MODEL ***********************					
LPM/UC	60	1.01	84	0.81	57
LPM/gama	60	1.21	82	1.32	61
LPM/Nash	60	1.01	76	0.83	64
MULTIPLE INPUT **************					
MILM/VC (Disc./Rain)	5/15	1.06	90	1.27	72
MILPM/UC		1.00	92	1.13	77
MILPM/Nash			90		76
MILPM/Diff. Eq.		1.01	63	0.91	64
		1.00	96	0.99	93
NONLINEAR MODEL ***************					
SINLM/Meixner		1.22	48	0.96	37
SINLPM/Meixner		1.01	80	0.84	62
SILPM/API		1.01	81	0.77	78

Table 2 Summary of conceptual models applied

			SMAR MODEL **********				CALIBRAT.		VERIFIC.	
Layer	Memory	C	Z	Y	H	T	rat.	R%	rat.	R%
25	45	1.6						-63		-66
25	45		531					-13		-66
25	45			7.74				36		24
25	45				0.41			47		31
25	45					0.73		-8		-44
25	45	1.0	1000	7.82	0.42	1.36	1.56	29	1.29	31
25	45	1.0	433	43.17	0.34	1.00	1.55	30	1.34	35
			SMAR-EFF ********							
25	45	1.0	433	43.17	0.34	1.00	1.55	30	1.34	35
			NAM					89		41
			XINANJIANG					64		-22

5. DISCUSSION OF THE RESULTS

Fig.5 shows a response function of the simple linear unconstrained model while Fig.6 shows that of volume constrained linear model. From these figures it can be seen that the data are seasonal (two peaks in the response function). None of the linear models gave an appreciable efficiency. The unconstrained linear model gave an efficiency of 71% during calibration and 50% during verification. Higher efficiencies are obtained when an updating linear model is applied. This gave an efficiency of 97% during calibration and 93% during verification.

For each of model applied, error analysis were carried out. Simple linear models gave much errors for low flow and high flows as shown in Fig.7 and Fig.8. Other models showed similar results for instance Fig.9 and Fig.10 are example of MILM and LPM(Api-Meixner) respectively.

Seasonal model gave an efficiency of 50% during calibration and 59% during verification. This shows that the data are not highly seasonal. Modelling of departures (perturbations) from the seasonal means gave an efficiency of 60% during calibration and 84% during verification.

Despite of the fact that conceptual models group together more obvious non linear operations in addition to evaporation data, none of the conceptual models gave an appreciable result. The NAM model gave an efficiency of 89% during calibration and 41% during verification.

With the multiple input model, an efficiency of 91% during calibration was achieved and 72% during verification. The results obtained with this model are a bit higher than those of single input models.

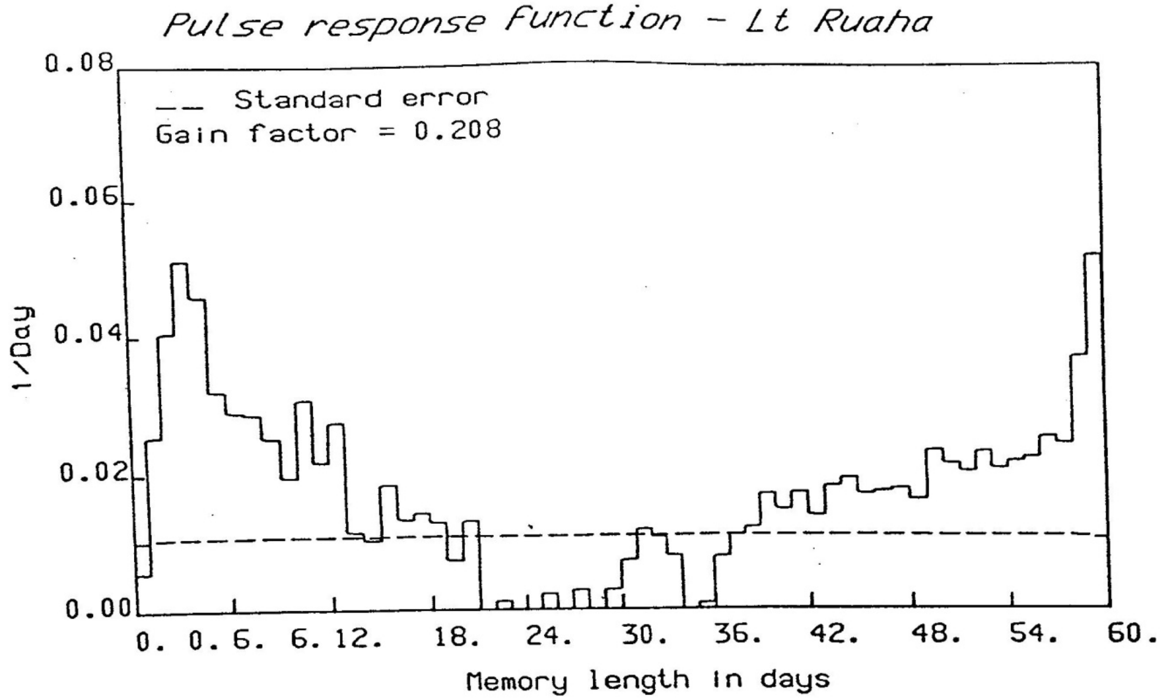


Figure: 5 Standardised pulse response of the Linear model derived by ordinary least squares

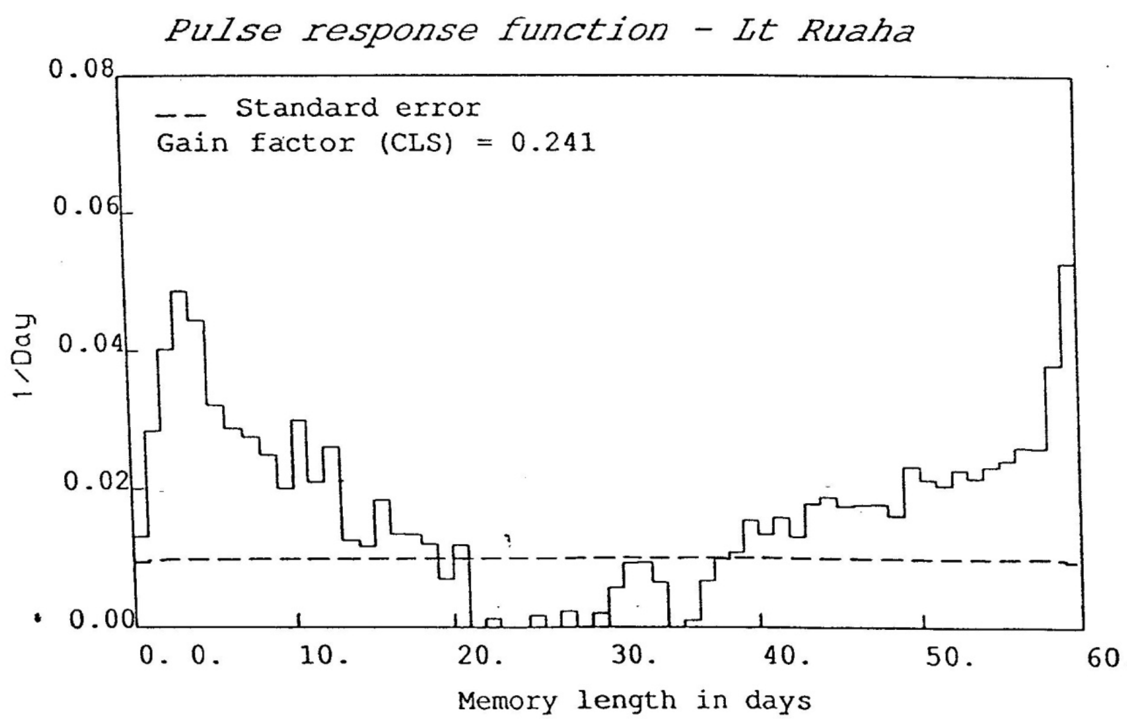


Figure: 6 Standardised pulse response of the Linear model derived by volume constrained least squares

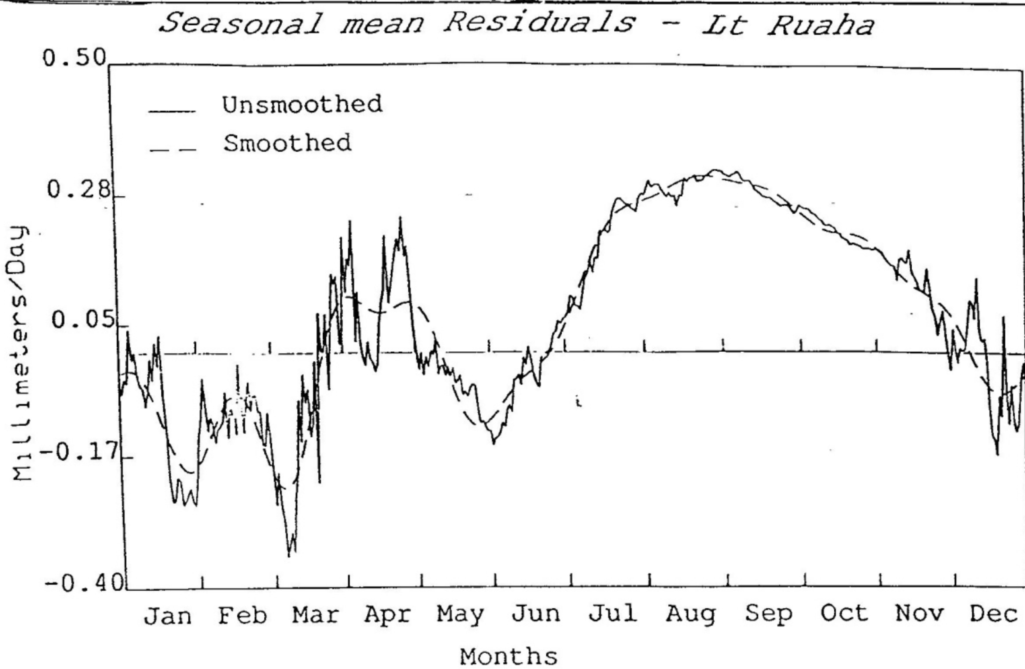


Figure: 7 Smoothing by Fourier analysis (10 harmonics)
Model: SILM/UC

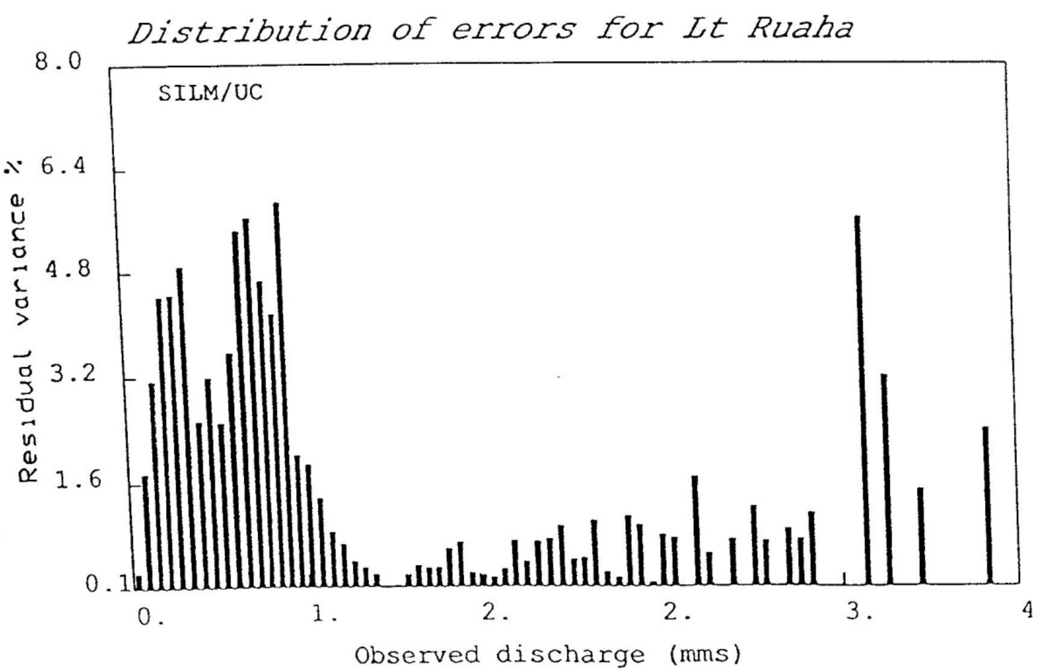


Figure: 8 Scatter diagram of the residuals and the observed discharges.

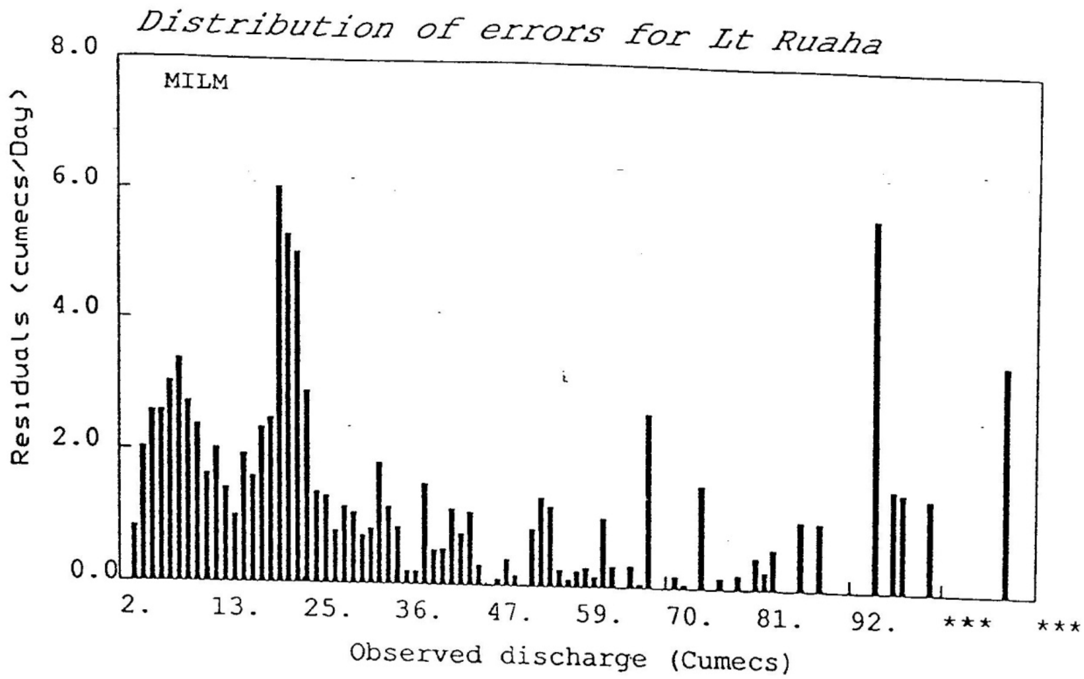


Figure: 9 Scatter diagram of the residuals and the observed discharges.

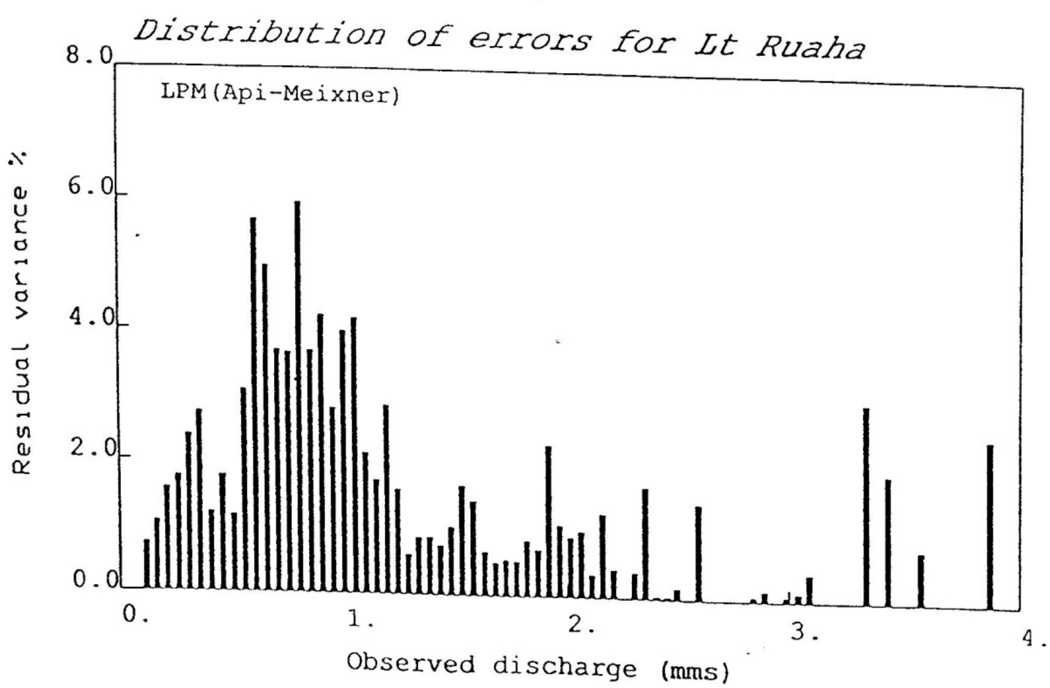


Figure: 10 Scatter diagram of the residuals and the observed discharges.

6. CONCLUSION

The multiple input single output linear perturbation gave an improved result. This is because of the inclusion of discharge data upstream as one of the input. The model efficiency increased considerable as compared to using six rainfall measuring stations. This fact encourages installation of more and more discharge measuring stations to a number of tributaries rather than introducing as many as possible rainfall gauging(measuring) stations.

ACKNOWLEDGMENT

The study was conducted at the University College Galway, Ireland for a period of April - June 1991. The author is very grateful to the Irish Government for providing the fellowship.
I'm very indebted to the staff of the Department of Engineering Hydrology, Galway for their suggestions, guidance, introductory lectures in runoff modelling and making the programs (software) available for the study.

REFERENCES

1. Kachroo R.K., 1991. Lecture note , 4th International workshop on river flow forecasting, University College Galway, Ireland.

2. Dooge J.C.I., 1973. Linear theory of hydrologic system, USA, Dept. of Agriculture, Technical Bulletin No. 1468.

3. Dooge J.C.I., and Garvey R.J., 1978. The use of Meixner functions in the identification of heavily damped system. Proc. R. Irish Acad. Section A, Vol. 78 No. 18.

4. Liang G.C., 1986. Linear models for multiple inflows single outflow routing in real time, PhD thesis, Dept. of Engineering hydrology, University College Galway, Ireland.

Appendix 1.

River Little Ruaha — Sheet No: 1

At IHIMBU

Station No 1 KA 21A — Established 8/4/1957

Coordinates Lat 7°53'00" S — Long 35°48'00" E

Altitude 1550 m. — Catchment Area 2480 sq. km.

Description of the Ctchment: Woodland with flat slopes.

Station Details:

1. Staff Gauges:

Range 0.00 m - 5.00 m — A.D.Z.G.R.L 0.00 m.

Type of Gauges Standard vertical — M.S.L.Z.G.R.L -

2. Automatic Recorders: Ott - Float type

3. Bench Mark Red ring painted on the rock near the recorder.

B.M. Assumed Datum 3.356 m.

B.M.M.S.L. Datum -

4. Control: Complete rock bar with some projecting rocks d/s.

5. Access: Accessible throughout the year 26 kilometers from Iringa on Dabaga loop.

Records:

Extremes:

Max. Recorded Discharge 129.44 on 6/4/68 W.L. 4.91

Min. 3.25 on 14/11/69 " 1.13

Remarks:

1 KA 21 was closed on 23/12/67 soon after closure 1 KA 21A was opened.