Water Budget and Performances of Three Rainfall – Runoff models for Upper Adhaim River Basin

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الخلاصة

استخدمت ثلاثة نماذج هيدرولوجية لنمذجة وتحليل العلاقة اليومية بين الامطار والسيح السطحي لحوض نهر اعالي العظيم التي تعتمد على مبدأ الهيدروغراف القياسي. ان النماذج المستخدمة هي: النموذج الخطي البسيط (SLM)، نموذج عامل المكسب للمتغير الخطي (LVGFM) والنموذج الغير خطي (NLM). اظهرت الدراسة بعد استخدام خمسة معايير لتقييم كفاءة النماذج بان نموذج (SLM) اظهر علاقة ضعيفة بين المطر والسيح الخطي. وان الفرضيات الخطية صحيحة فقط للايام السابقة الاربعةالاولى. ان نتائج العلاقة الغير خطية بين المطر والسيح السطحي كبيرة وتلاحظ بشكل واضح لنماذج (LVGFM) و(NLM). ان كلا النموذجين (LVGFM) و(NLM) قد حققا نتائج مقبولة عند (17) يوم سابقاً وعلى ايه حال فان نموذج (LVGFM) قد حقق نتائج افضل بعض الشيء مقارنة بنموذج (NLM)، وعلى هذا الاساس فقد استخدم نموذج (LVGFM) للتنبؤ بالجريان السيح السطحي. اظهرت نتائج الدراسة التقارب المقبول بين السيح السطحي الحقلي والنظري من حيث الوقت والحجم، كما خلصت دراسة الموازنة المائية لحوض نهر اعالي العظيم بان 73.4% من المطر السنوي يكون على شكل تبخر ونتح و 8.0% على شكل ارتشاح وان 18.6% يقاس على شكل سيح سطحي مباشر.

Abstract

An applied hydrological models were performed to model the rainfall-runoff relationship for Upper Adhaim River Basin. Three lumped integral models (hydrologic models) based upon the concept of the unit hydrograph were applied to analyze the rainfall-runoff relationship on a daily basis. These models are: the Simple Linear Model (SLM), the Linear Variable Gain Factor Model (LVGFM), and the Non-Linear Model (NLM). Five performance evaluation criteria have been used in this study. The application results of the (SLM) model showed a weak rainfall-runoff relationship. It was demonstrated that the linear assumption is valid only for the first four antecedent days. A considerable non-linear rainfall-runoff relationship was clearly observed from the results of (LVGFM) and the (NLM) models. Both models were satisfactorily identified at system memory of (17) antecedent days. However, the (LVGFM) was slightly superior to the (NLM). The (LVGFM) identified at system memory of seventeen antecedent days was used to simulate runoff flows. The simulation results show an acceptable applicability for the (LVGFM) in terms of simulating runoff events in time of its occurrence and volumetric fitness. The water budget for Upper Adhaim River Basin showed that an average of 73.4% from annual rainfall was evapotranspired, 8.0% was infiltrated and 18.6% was observed as direct runoff.

1. Introduction

Upper Adhaim River Basin, Fig. (1) is located in Northern Iraq between the Iraq grid E 44°00′ and E 45°15′, N 34°30′ and N 35°45′. It comprises an area of 11600km^2. The study area lies in the foothills of the mountains which culminate in the Zagros chain to the east. To the north and south, the study area stops at the limits of the lesser Zab and Diyala River basins; respectively. To the west, the last small hills before the Vast Kirkuk-Adhaim plain mark the lower limit of the basins of the three main tributaries of the Adhaim River, the Khassa, Tawq and Tuz-Chais which are the subject of the present study.

Previous hydrological study for Upper Adhaim River Basin was conducted by Sogreah consulting Engineers(1). A relationship between the precipitation and runoff for Adhaim River above narrow was established, Eq.(1).

$$y = -1035.3 + 75.46\,x \quad \text{.....................(1)}$$

where: y is the annual runoff (*10^6 m^3), and x is the total precipitation index in (mm).

Due to existing of several models, hydrological studies in the perspective of assessment of water surface resources for Upper Adhaim River basin are still needed.

The objective of this study is to obtain an approximate quantification for the water budget and to evaluate the performance and model the rainfall-runoff relationship for Upper Adhaim River Basin.

2. Water Budget

The general equation for the water budget was calculated using the following formula:

$$P + R_{in} - R_{out} + R_g - E_s - T_s - I = \Delta S_s \quad \text{.................(2)}$$

where P is the total precipitation, R_{in} is the surface inflow, R_{out} is the surface outflow, R_g is the groundwater effluent to the surface, E_s is the evaporation from the surface, T_s is the transpiration from the surface storage, I is the total infiltration and ΔS_s is the change in surface storage.

In order to facilitate the quantification of the water budget in the Upper Adhaim River Basin, the above equation was simplified according to the following assumptions:

1. The flow components R_{in}, R_{out} and R_g are reduced to R as direct runoff only.
2. The evaporation components E_s and transpiration components T_s are combined as evapotranspiration ET.
3. The storage component ΔS_s does not change during the year, implying that $\Delta S_s = 0$.

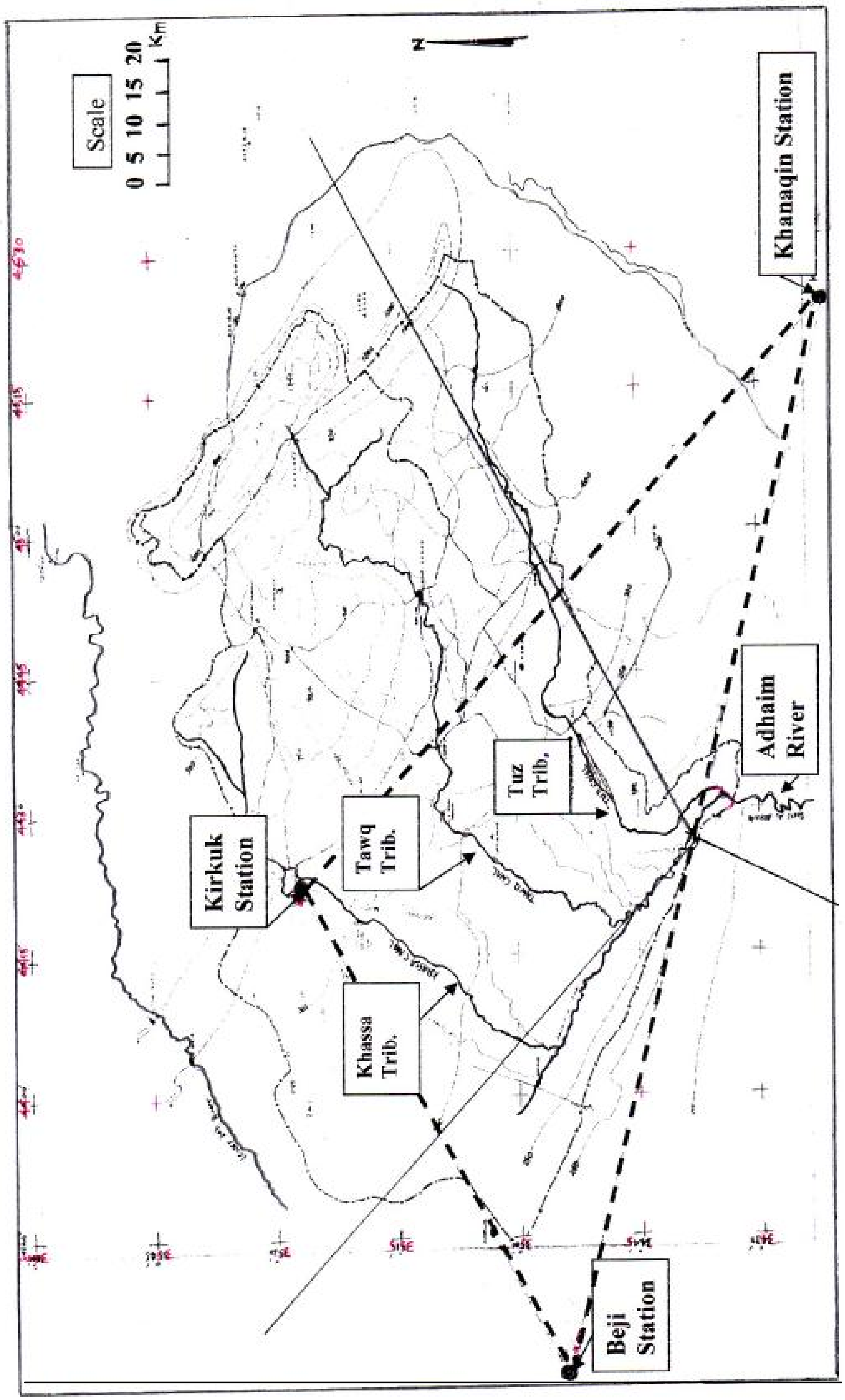


Fig.(1): Location of Upper Adhaim River Basin and Rain Gages.

The surface hydrological budget of equation (2) is then reduced to the following from:

$$P = R + ET + I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where P is the rainfall, R is the direct runoff, ET is the evapotranspiration and I is the infiltration. All terms are in cubic meter unit.

3. Rainfall-Runoff Modeling

Owing to the complex nature of rainfall-runoff processes determined by a number of highly interconnected water/energy and vegetation processes at various spatial scales, hydrologists rely on their own understanding of the system gained through interaction with it, observation and experiments. This process is known as perceptual modeling (Beven[2]). Perceptualization of a hydrologic system leads the modelers to a variety of ways to classify rainfall-runoff models from deterministic to stochastic models, from physically-based (white-box) to (black-box) or empirical and to conceptual models, and the most distinctive from lumped models to distributed models (Clarke[3]; Beven[4]; Wheater[5]; Refsgaard[6]; Beven[2]). In lumped models, the entire river basin is taken as one unit where spatial variability is disregarded. On the other hand; a distributed model is one which accounts for spatial variations of variables and parameters, thereby explicit characterization of the processes and patterns is made (Beven[4]; Refsgaard[6]; Smith[7]).

Three system-theoretic black-box models, Simple Linear Model, Linear Variable Gain Factor Model and Non-Linear Model were used. For completeness, brief descriptions of these models are provided this section:

The Simple Linear Model (SLM)

The intrinsic hypothesis of the SLM, introduced by Nash and Foley [8], is the assumption of a linear time- invariant relationship between the total rainfall R_i and the total discharge Q_i.

In discrete form, the SLM is expressed by the convolution summation relation [Kachroo and Liang[9]],

$$Q_i = \sum_{j=1}^{m} R_{i-j+1} h'_j + e_i = G \sum_{j=1}^{m} R_{i-j+1} B_j \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where $\sum_{j=1}^{m} B_j = 1$ and Q_i and R_i are surface runoff (excluding base flow) and rainfall respectively at the i-th time step, h'_j is the j-th discrete pulse response ordinate or weight, m is the memory length of the system, G is the gain factor, and e_i is the forecast error term.

The Linear Variable Gain Factor Model

The (LVGFM) proposed by Ahsan and O'Connor [10] for the single-input to single-output case, involves only the variation of the gain factor with the selected index of the prevailing catchments wetness, but not the shape (i.e. the weights) of the response function. Using a time-varying gain factor G_i, the model output has the structure:

$$Q_i = G_i \sum_{j=1}^{m} R_{i-j+1} B_j \qquad \text{where} \sum_{j=1}^{m} B_j = 1 \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

In its simplest form, G_i is linearly related to an index of the soil moisture state Z_i by the equation $G_i = a + bZ_i$, where a and b are constants.

The value of Z_i is obtained from the outputs of the SLM, operating as an auxiliary model, using:

$$Z_i = \frac{\hat{G}}{\bar{Q}} \sum_{j=1}^{m} R_{i-j+1} \hat{h}_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where $\hat{G}$ and $\hat{h}_j$ are estimates of the gain factor and the pulse response ordinates respectively of the SLM and $\bar{Q}$ is the mean calibration surface runoff (discharge). The discrete forms and the subsequent solution of the solution of the SLM and the LVGFM are shown in Figs. (2) and (3).

3.3 Non-Linear Model

The constrained of linearity is simplified by representing the system as time invariant non linear system written in the form of discrete convolution and solved by the ordinary least squares technique (Amorocho and Brandstetter[11]):

$$Q_i = \sum_{j=1}^{m} h_j . R_{i-j+1} + \sum_{j=1}^{m} \sum_{k=1}^{m} g_{ik} . R_{i-j+1} . R_{i-k+1} \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where h_j is the linear kernel function and g_{ik} is the non linear kernel function. The first term, known as the first order, is the familiar Simple Linear Model (SLM). The additional terms or orders of expanding dimensionality reflect the interdependence and interaction among the system components, mainly those which are considered to be time invariant and which depend ultimately on rainfall input.

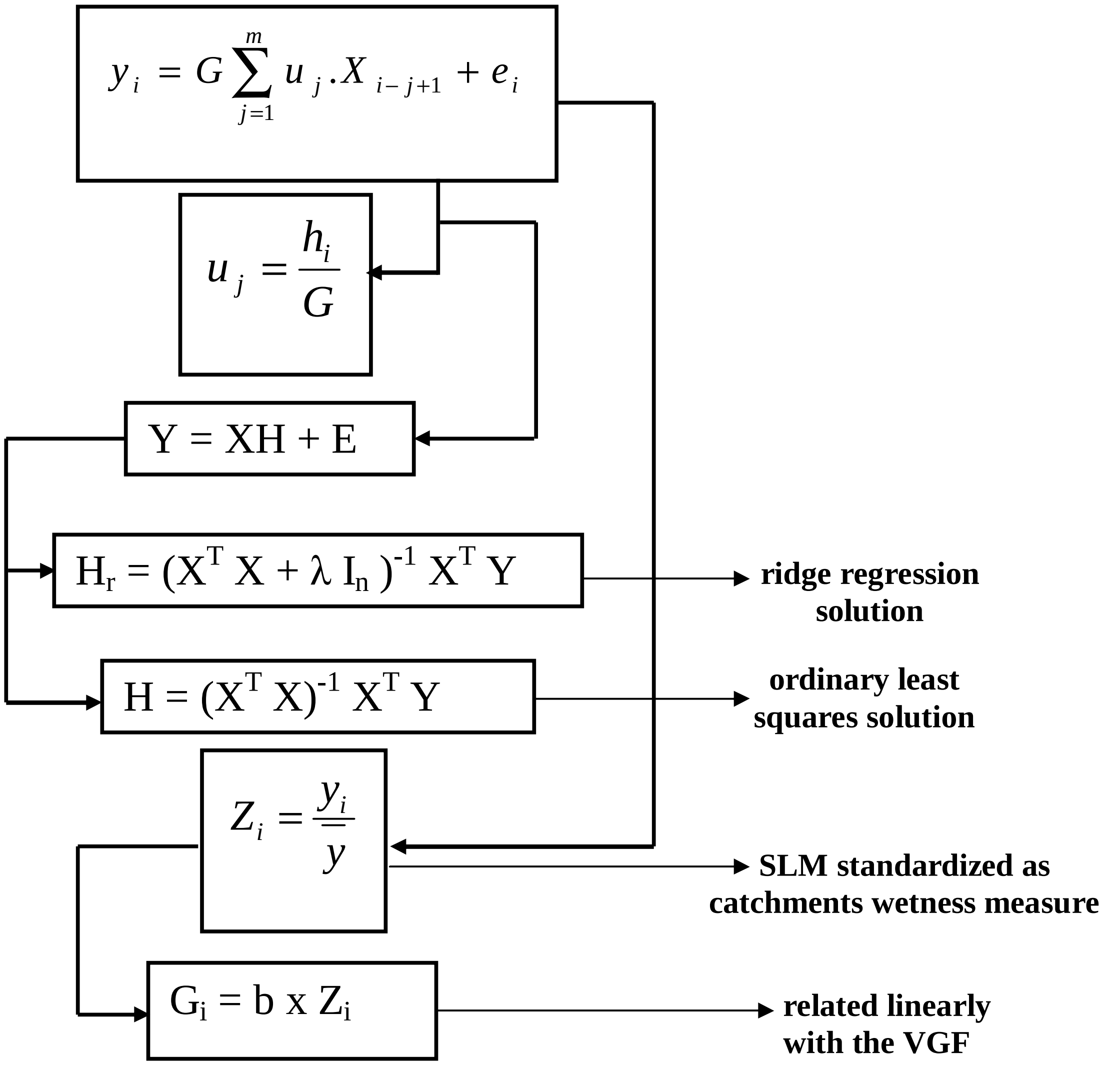


Fig. (2): The Discrete Form of the (SLM) Model.

λ is eigen value

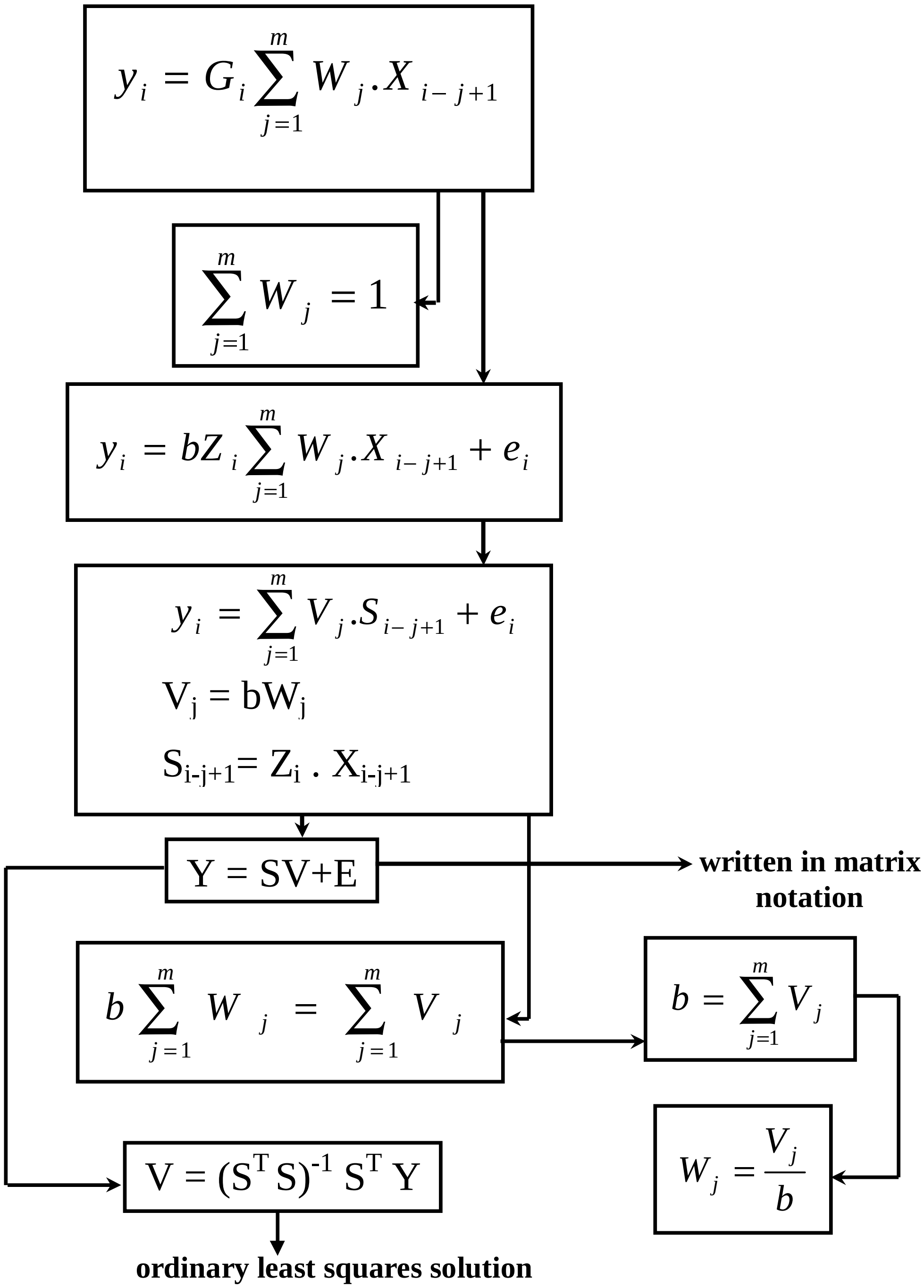


Fig. (3): The Discrete Form of the (LVGFM) model

The solution of the Non-Linear Model may be encountered by two main obstacles, for a hydrologic system, with a very long memory, formidable numerical difficulties arise in the inversion of enormous matrix. The other obstacle is due to the nature of the rainfall and runoff records which may not be long enough to provide a representative sample population and all information essential for satisfactory identification. Therefore, it is justified to approximate the kernel functions by a proper procedure. The most commonly used technique involves kernel expansion in series of orthogonal functions, thus reducing the solution of the equation to the determination of the coefficients of orthogonal expansion which are expected to be considerably smaller than the number of values demanded by the original data matrix (Papazafiriou(12)).This method was applied without difficulties on experimental and natural catchment and gave reasonable predications for extreme floods by Kernels estimated from few historical floods (Muftuoglu, (13); Kachroo(9)).

The discrete form of the Non-Linear Model (NLM), the orthogonal expansion and the subsequent numerical solution are shown in Fig. (4).

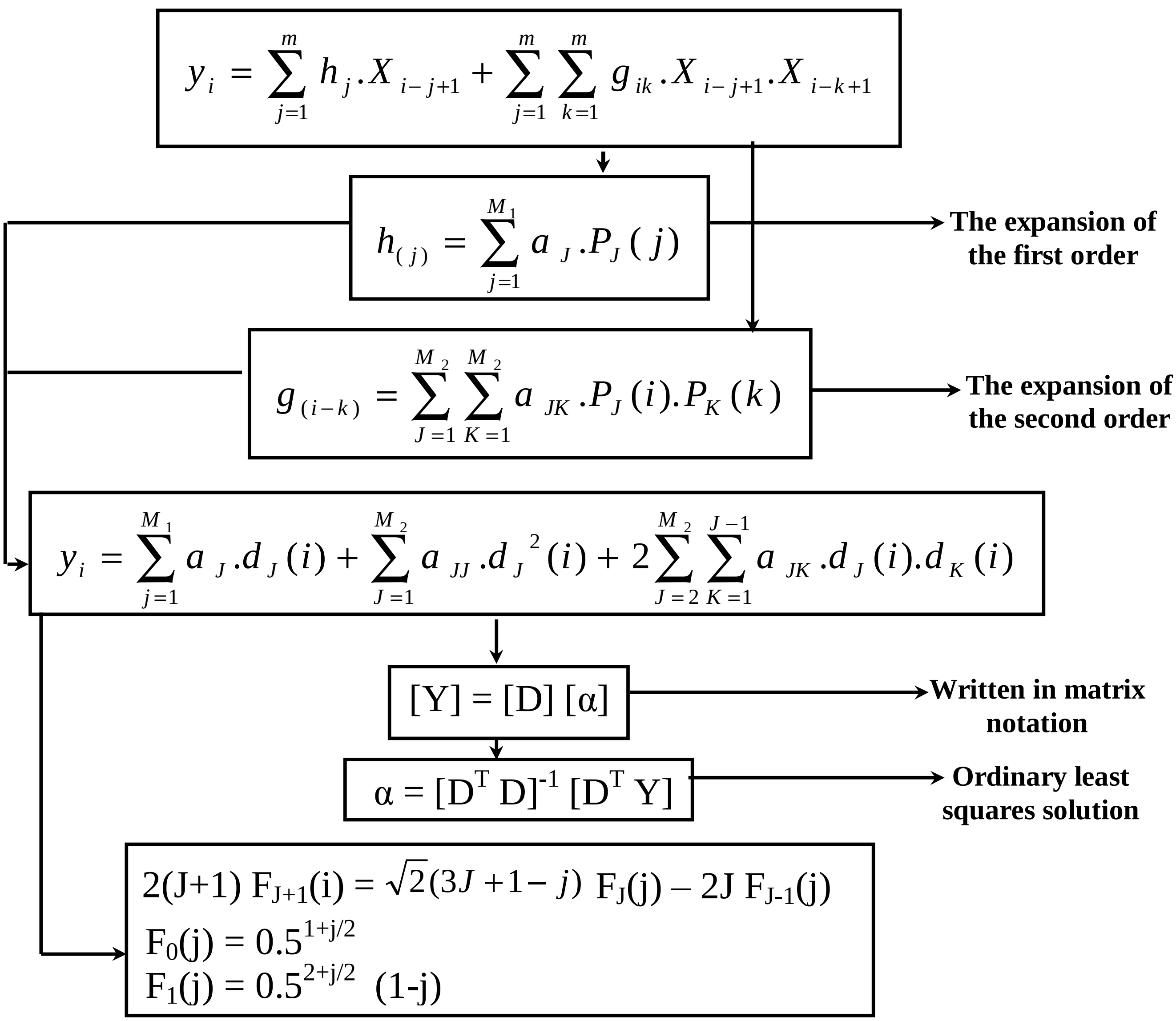


Fig. (4): The Discrete Form and the Numerical Solution of (NLM) model.

4. Methodology

4.1 Input Data

4.1.1 Rainfall

Three rain gauges were selected as fixed network. The area of influence for each rain gauge was determined involving Thiessen methods, Fig. (1). The selected rain gauges have complete records for twenty hydrologic years, containing all essential information and historic records that occurred during the period 1977 to 1996 [Ministry of Sciences and Technology(14)].

4.1.2 Runoff

The direct runoff measurements at Ingana-Narrows are available from the records of General Directorate of Water Resources Management- Ministry of Water Resources(15), as daily average flows expressed in m^3/sec. The direct runoff was obtained by subtracting the base flow from the total stream flow. The obtained base flow was considered equal to the base flow at the beginning of storm runoff and constant throughout storm duration.

4.1.3 Evapotranspiration

The data of three evaporation stations, located inside the basin were considered. The potential evapotranspiration was calculated mainly from A-pan evaporation multiplied by factor representing the ratio between Penman potential evapotranspiration values and the A-pan evaporation.

4.2 The Water Budget

To determine the water budget for Adhaim River Basin in accordance with equation (3), the monthly rainfall for each station and runoff volumes were calculated for each year in the record. As for the evapotranspiration, it is reasonable to consider the average monthly values since it does not vary greatly from year to year. It is irrelevant, however, to consider the potential evapotranspiration as actual evaporation, especially in arid and semi arid regions where the potential evapotranspiration largely exceeds the monthly and annual rainfall and where rainfall is not uniformly distributed throughout the catchment. Therefore, to get an approximate actual evapotranspiration, it is advisable to divide the basin into smaller sections.

For this purpose, the areas of influence obtained by Theissen method were considered as suitable divisions, the potential evapotranspiration from each polygon was assigned to the nearest evaporation station. The actual evapotranspiration from any polygon may have two upper limits. The first limit is equal to the monthly rainfall as it is exceeded by the potential evapotranspiration. The second limit is equal to the potential evapotranspiration as it is exceeded by the monthly rainfall. The infiltration can then be determined by subtracting the monthly runoff and monthly evapotranspiration. If a negative infiltration values occurred, then the evapotranspiration is adjusted so that the negative infiltration values are eliminated.

4.3 The Rainfall-Runoff Modeling

4.3.1 Data Preparation

The rainfall and runoff were applied as daily volumes in Million Cubic Meters (MCM). The runoff events were accommodated with twenty five antecedent rainfall days (the day of runoff onset and twenty four preceding days) as an arbitrary system memory.

In most applications, the tendency has been to split the record into calibration period that includes most available data and a shorter verification period. In this type of sampling, the verification period may not include sufficient information for accurate verification (Kachroo(16)). A more convenient approach is the two-way calibration-verification analysis suggested by Party and Marino (17), where the data are split into two groups, the first group is used for calibration and the second group is used for verification, then the reverse analysis is performed.

To perform the two-way calibration-verification analysis, the selected hydrological years were divided equally into two groups. The division was carried out in such a way that each group will provide a similar range of rainfall-runoff characteristic. The hydrological years for calibration are from (1976-1977; 1978-1979; 1980-1981; 1982-1983; 1984-1985; 1985-1986; 1987-1988; 1989-1990; 1991-1992; 1993-1994) and for verification are from: (1977-1978; 1979-1980; 1981-1982; 1983-1984; 1986-1987; 1988-1989; 1990-1991; 1992-1993; 1994-1995; 1995-1996).

4.3.2 The performance evaluation criteria

Five performance evaluation criteria have been used in the study [Legates and McCabe(18); Beran(19)]:

a- The coefficient of efficiency is defined by the dimensionless expression:

$$R^2 = 1 - \frac{MSE}{F_0} \quad \text{……………………..(8)}$$

with $$F_0 = \frac{1}{N}\sum_{1}^{N}[(Q_0)_i - \bar{Q_c}]^2 \quad \text{…………..(9)}$$

and $$MSE = \frac{1}{N}\sum_{1}^{N}[(Q_0)_i - (Q_e)_i]^2 \quad \text{…………(10)}$$

MSE being the mean square error. In expression (8), and (9), $(Q_o)_i$ is the observed discharge and $(Q_e)_i$ is the estimated discharge at the ith time step, N is the total number of discharge values and $\bar{Q}_c$ is the mean of the $(Q_o)_i$ series over the calibration period.

b- The index of agreement, IOA, is defined as:

$$IOA = 1.0 - \frac{\sum_{1}^{N}[(Q_o)_i - (Q_e)_i]^2}{\sum_{i=1}^{N}(\left|(Q_o)_i - \bar{Q}_c\right| + \left|(Q_e)_i - \bar{Q}_c\right|)^2} \quad ....(11)$$

in which the numerator is N times the MSE and the denominator is called the potential error.

c- The coefficient of determination, r^2, is given by:

$$r^2 = \left[\frac{\sum_{1}^{N}[(Q_o)_i - \bar{Q}_o][(Q_o)_i - \bar{Q}_e]}{\left\{\sum_{i=1}^{N}[(Q_o)_i - \bar{Q}_o]\right\}^{0.5}\left\{\sum_{i=1}^{N}[(Q_e)_i - \bar{Q}_e]\right\}^{0.5}}\right]^2 \quad ....(12)$$

where $\bar{Q}_o$ and $\bar{Q}_e$ are the mean of the observed and the estimated discharge data series over the data period considered.

d- The index of volumetric fit, IVF, the ratio of the total volume of $(Q_e)_i$ to the total volume of $(Q_o)_i$:

$$IVF = \frac{\sum_{i=1}^{N}(Q_e)_i}{\sum_{i=1}^{N}(Q_o)_i} \quad ....(13)$$

e- The relative error of the peak (R.E) is defined as:

$$R.E = \frac{\left|(Q_p)_e - (Q_p)_o\right|}{(Q_p)_o} \quad ....(14)$$

where $(Q_p)_o$ and $(Q_p)_e$ are the observed and estimated peak flows, respectively.

4.3.3 Parameter Identification

For the three models used in this study, the system memory, the first and second order of expansion (M1 and M2) are the common parameters needed to be identified. These parameters can be identified by performing the two-way calibration-verification analysis at varying values of system memories (5-25) days and varying values of M from (1-10) (to minimize the efforts, it is reasonable to reduce M_1 and M_2 to one parameter by setting $M=M_1=M_2$).

5. Model Tests results and Discussion

5.1 The hydrologic Budget

The four parameters of the hydrological budget prescribed in equation (3) are determined and summarized in Table (1). An average of (73.4%) from the annual rainfall of Adhaim River Basin was found to be evaptranspired, (8.0%) infiltrated and (18.6%) observed as direct runoff.

Table (1): The annual hydrological budget for Adhaim River Basin

Years	P (MCM)	ET (MCM)	DR (MCM)	BF (MCM)	TR (MCM)	I (MCM)
1976-1977	3422.55	2844.34	258.33	31.54	289.87	319.88
1977-1978	2565.24	2095.90	262.1	56.76	318.86	207.94
1978-1979	3365.23	2502.59	717.0	41.94	758.86	145.64
1979-1980	4009.16	3363.62	363.88	41.94	405.82	281.66
1980-1981	5262.83	4488.10	735.33	39.42	774.75	39.40
1981-1982	5455.27	3870.85	1188.72	86.72	1275.44	395.70
1982-1983	2244.11	1818.35	374.33	47.3	421.63	51.43
1983-1984	2828.09	2323.56	123.94	31.54	155.48	380.60
1984-1985	3303.62	2685.70	590.93	44.15	635.08	26.99
1985-1986	3217.22	2663.79	310.01	37.84	347.85	243.42
1986-1987	1781.73	1423.85	92.50	57.71	150.21	265.39
1987-1988	3480.33	1144.98	1460.21	73.48	1533.69	875.14
1988-1989	1808.06	1061.88	554.04	236.52	790.56	192.14
1989-1990	2824.19	2320.16	422.92	210.03	632.45	81.61
1990-1991	4349.74	3667.26	490.51	134.03	624.54	191.97
1991-1992	6839.84	5323.04	1215.61	283.82	1499.43	301.19
1992-1993	4096.58	2183.16	1284.29	346.9	1631.19	629.13
1993-1994	3966.6	2562.16	1022.63	63.07	1085.7	381.81
1994-1995	3212.4	1611.12	1077.06	693.79	1770.85	524.22
1995-1996	4178.39	3033.43	904.52	236.52	1141.04	240.44
Average	3610.59	2649.39	672.42	139.75	812.169	288.78

The ET values do not respond linearly to the increase in rainfall. This can be attributed to the rainfall distribution throughout the hydrological year since the main portion of the annual rainfall occurred during December till April (ET in any month will not exceed an upper limit defined as the potential evapotranspiration (ET_p)).

5.2 <u>The analysis of the LVGFM model</u>

The results of the two-way calibration-verification analysis of the LVGFM are shown in Table (2). Better performance was observed in the calibration period of the coefficient of efficiency, where the verification periods respond positively to the other efficiency evaluations. The values of the efficiency evaluation, increased until it reached its highest values at approximated value t=17 system memory before it finally deteriorated at t=25 system memory. The linear assumption is valid only for the first four antecedent days. Due to these results, it is reasonable to consider the model calibrated at t=17 system memory as a satisfactory identification for the (LVGFM).

Table (2): Efficiency Evaluation Criteria results for the calibration and verification (LVGFM model)

Efficiency evaluation	analysis	t=5	t=10	t=15	t=20	t=25
R^2	Calibration	0.643	0.812	0.857	0.845	0.792
	Verification	0.626	0.734	0.790	0.765	0.723
IOA	Calibration	0.714	0.816	0.974	0.879	0.848
	Verification	0.685	0.843	0.943	0.907	0.853
r^2	Calibration	0.678	0.766	0.865	0.849	0.809
	Verification	0.695	0.753	0.853	0.817	0.791
IVF	Calibration	0.736	0.785	0.882	0.859	0.807
	Verification	0.989	1.056	1.285	1.284	1.159

5.3 <u>The application of the NLM Model</u>

No optimal values for the system memory (t) and the parameter of expansion parameter (M) were observed. The coefficient at efficiency (R^2) in the calibration periods increased systematically with the parameter of expansion. The efficiency coefficients of the verification period oscillate around an average value, Table (3).

The following regression model was derived for the efficiency coefficient (R^2) of the calibration period (the predictor variables are the system memory (t) and the parameter of expansion (M))with 0.97 coefficient of determination:

$$R^2_{cal.} = 58.02 + 0.11t + 3.0M \qquad \text{.............................(15)}$$

The accepted satisfactory model of the (LVGFM) identified at t=17 system memory is slightly superior to that of (NLM) identified at t=17 system memory and M=8 parameter of expansion, Fig. (5).

5.4 Performances of the Three Models

Each of the three basic models is applied to each of the five values of system memories and (M), involving the use of calibration and verification periods. The results of the performances of the three models are shown in Table (4).

Table (3): The Coefficient of Efficiency (R^2) of the (NLM) Model for different values at (t) and (M)

t	M	R^2 (calibration)	R^2 (verification)
5	1	61.95	58.12
5	2	64.04	57.43
5	3	67.26	60.36
10	1	63.12	57.76
10	2	64.54	52.66
10	3	68.32	54.57
10	4	70.98	56.05
15	1	63.45	67.91
15	2	65.04	60.83
15	3	68.57	64.15
15	4	71.48	62.00
15	5	74.56	60.41
15	6	77.92	68.67
15	7	81.14	76.30
20	1	63.96	67.26
20	2	65.54	59.37
20	3	69.04	64.11
20	4	71.98	62.01
20	5	74.64	62.74
20	6	78.42	59.28
20	7	80.91	57.53
20	8	84.86	72.64

Table (4): Calibration and verification Results for the System Memory (t =17).

Model	R^2	IOA	r^2	IVF	RE	Rank
Calibration						
SLM	0.704	0.904	0.707	1.076	0.517	3
LVGFM	0.867	0.965	0.873	0.870	0.005	1
NLM	0.841	0.955	0.841	1.004	0.090	2
Verification						
SLM	0.706	0.919	0.737	1.372	0.332	3
LVGFM	0.817	0.957	0.849	1.277	0.137	1
NLM	0.757	0.949	0.846	1.335	0.069	2

From these results, it is clear that the simulation performance of the SLM is, in each case, inferior to that of all other models. As expected, the LVGFM, which is a modification of the SLM, incorporating an element of linear variation of the gain factor G_i with the catchments wetness index Z_i at each time-step, performs consistently better than the SLM and NLM. The values of three performance evaluation criteria namely, the coefficient of efficiency, the index of agreement and the coefficient of determination, are very similar and consistent. The index of volumetric fit and the relative error of peak are more appropriate for use as auxiliary indices, when the performances of two or more models are indistinguishable on the basis of the first three. The value of the relative error of peak is a useful index in simulating events such as floods.

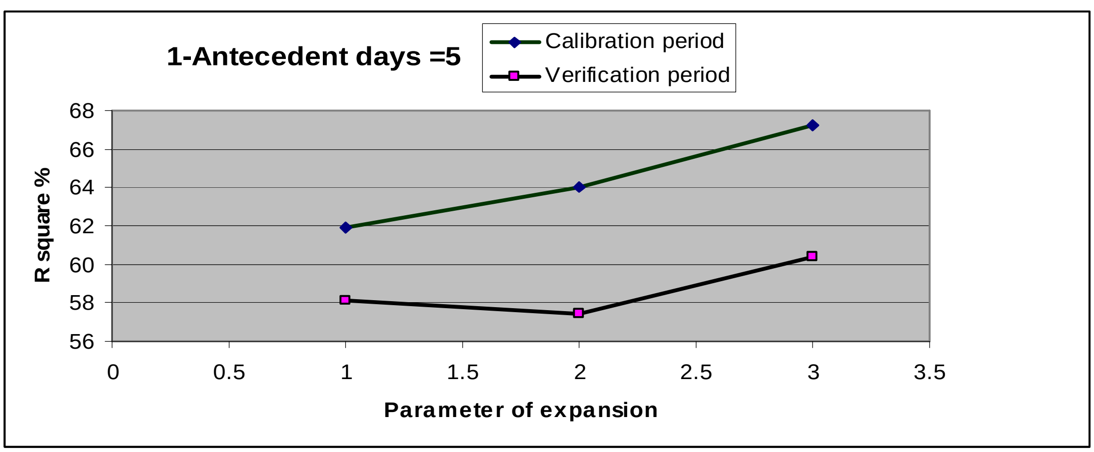
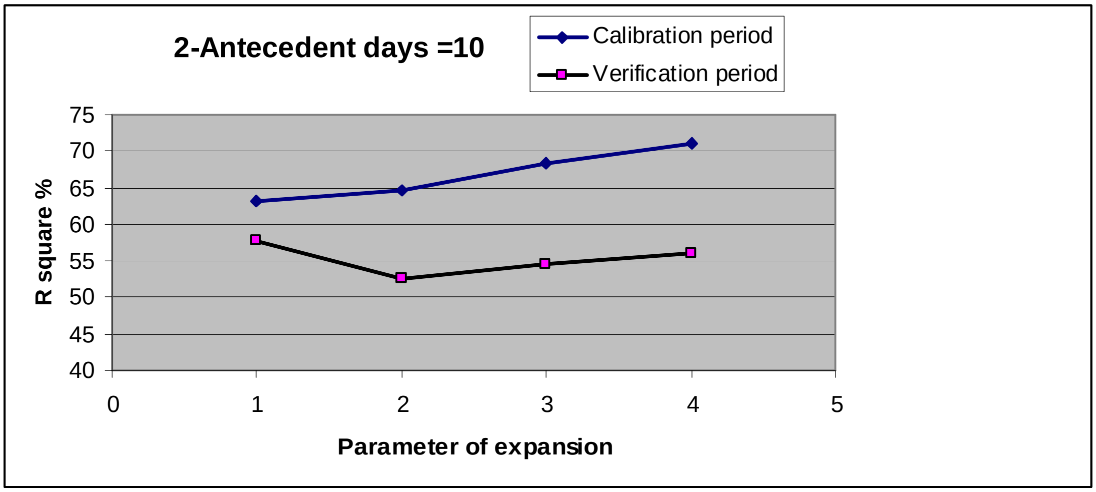
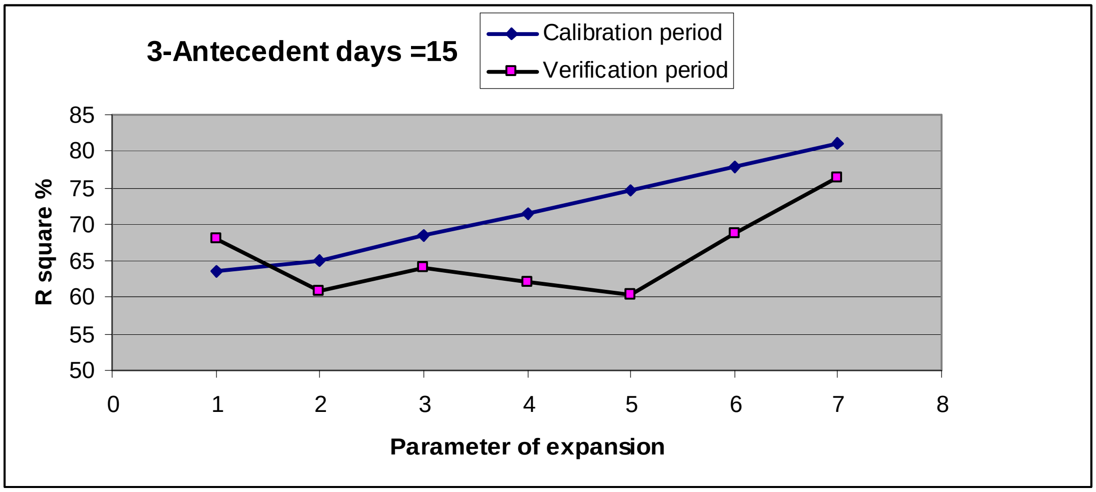


Fig.(5): The coefficient of Efficiency of the NLM model.





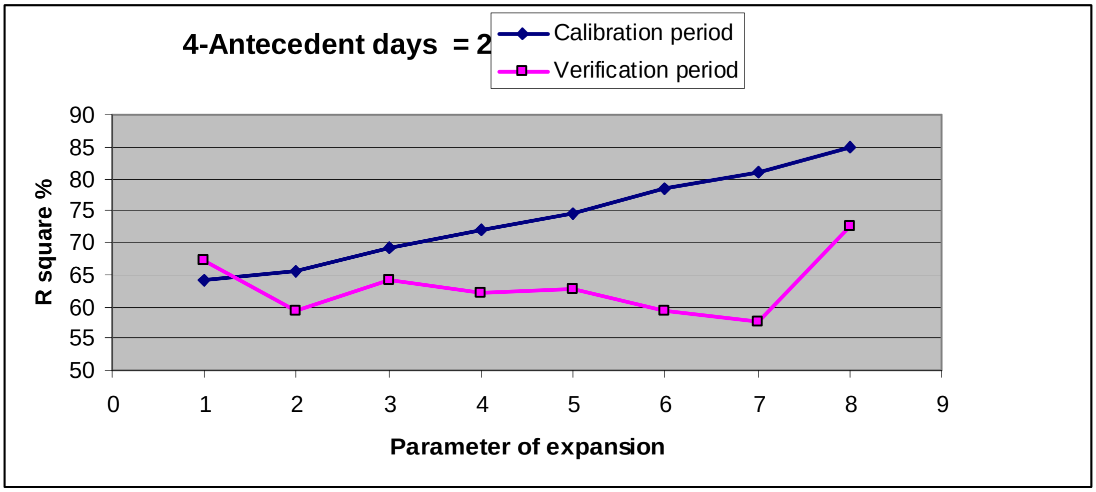


Fig.(5): Continued.

5.5 The Observed and Simulated Flows

The observed and simulated flows for the two periods are shown in Figs. (6) and (7), respectively.

In the calibration period, four peaks were observed, runoff volumes of 79.06, 28.0, 25.49 and 33.44 MCM. These peaks were predicted as 96.58, 17.90, 21.71 and 18.35 MCM, respectively. The observed total runoff volume during that period was 565.52 MCM and the predicated total volume was 514.8MCM, a volumetric fitness is about 91%.

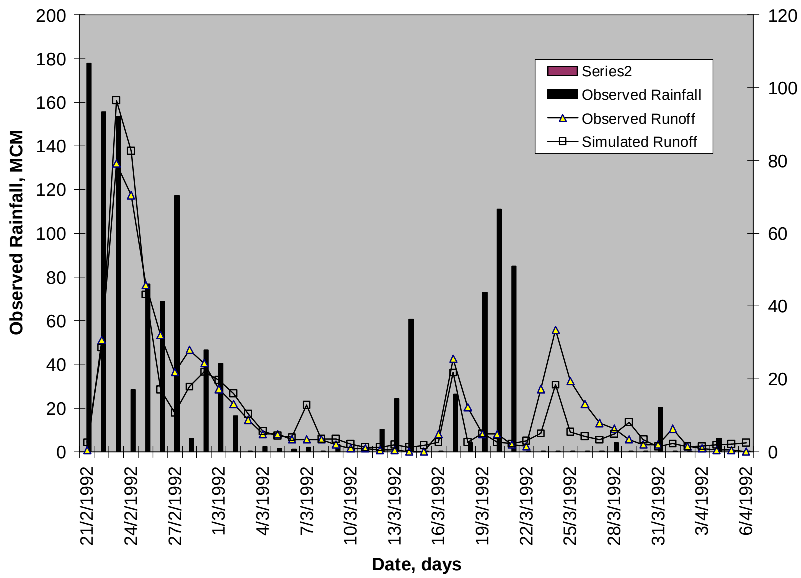


Fig.(6): Observed and Simulated Runoff and Observed Rainfall for LVGFM Model (Calibration Period) with a System Memory (t=17 days).

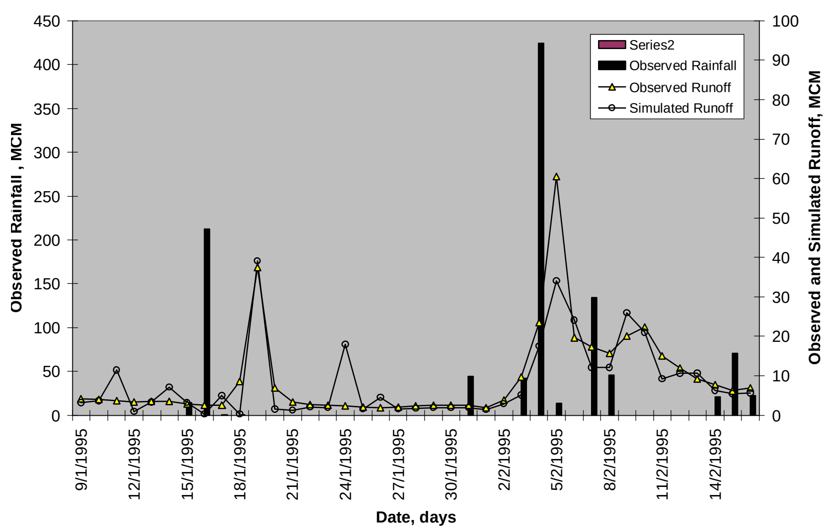


Fig.(7): Observed and Simulated Runoff and Observed Rainfall for LVGFM Model (Verification Period), with a system memory (t=17 days).

In the verification period, three peaks were observed, runoff volumes of 37.5, 60.57 and 20.55 MCM. These peaks were predicted as 39.12, 34.1 and 25.94, respectively. The observed total runoff volume during that period was (362.23)MCM and the predicted total runoff volume was (322.46)MCM, a volumetric fitness was of about 89%.A higher runoff magnitude was observed for the third peak, this is because the infiltrated water and other abstraction losses were minimized by the earlier absorbed rainfall water.

A remark deduced from the observed and simulated flows, the (17) antecedent days system memory concluded by the (LVGFM) should be considered as an upper limit rather than an optimal value. Any rainfall event during the first (16) days preceding the runoff onset can effectively contribute to the corresponding runoff event.

6. Conclusions

Applying the three models in this study may permit to draw the following conclusions:

- The water-budget for the Adhaim River Basin showed that an average of 73.4% from annual rainfall evapotranspired, 8% infiltrated, and 18.6% was observed as direct runoff.
- The evapotranspiration does not respond linearly to annual rainfall.
- The runoff is generated, mainly, at the second antecedent day, the magnitude of this generation depends on the catchment wetness condition which influenced by rainfall that occurred during (17) antecedent days past to the runoff onset. At high rainfall magnitudes, the runoff generation can occur at approximately (5) antecedent days past to the runoff onset.
- The values of three performance evaluation criteria namely, the coefficient of efficiency, the index of agreement and the coefficient of determination are very similar and consistent.
- The (LVGFM) model shows an acceptable applicability for represent the rainfall - runoff relationship for Adhaim River basin in terms of simulating the runoff event at the time of its occurrence and volumetric fitness.

References

1. Sogreah Consulting Engineering, 1981, "Hydrologic Study for Upper Adhaim River", Ministry of Irrigation, Iraq.
2. Beven, K.J., 2001, "Rainfall-Runoff Modeling-The Primer", Wiley: Chichester.
3. Clarke, K.J., 1973," A review of mathematical Models used in Hydrology", Journal of Hydrology, 19, 1-20.

4. Beven, K.J., 1985, "Distributed Models", Hydrologic Fore Casting, Wiley, New York.
5. Wheater, H.S., 1993, "Progress and directions in Rainfall-Runoff Modeling", John Wiley & Son, Pp.101-132.
6. Refsgaard, J.C., 1996, "Terminology, Modeling Protocol and Classification of Hydrological Model Codes, in Distributed Hydrological Modeling", water Science and Technology Library
7. Smith, M.B., 2004, "The Distributed Model Intercomparise Project (DMIP): Motivation and Experiment Design", J. Hydrol., 298, 4-26 ER.
8. Nash, J.E. and Foley, J.J., 1982, "Linear Models of Rainfall-Runoff System", Proceedings of the International Symposium on Rainfall-Runoff Modeling, USA, Water Resources Publication, Pp.51-66.
9. Kachroo, R.K., 1992, "River Flow Forecasting", part 3, Applications of Linear Techniques in Modeling rainfall-Runoff Transformation, J. Hydrol., 133: 41-97.
10. Ahsan, M. and O'Connor, K.M., 1994, "A simple-linear Rainfall-Runoff Model with a variable gain Factor", J. Hydrol., 155:151-183.

11. Amorocho, J. and Brand-Stetter, A., 1971, "Determination of Nonlinear Functional Response Functions in Rainfall-Runoff Processes", Water Resources Research, 7(5): 1087-1101.
12. Papazafiriou, Z.G., 1975, "Polynomial Approximation of the Kernel of closed Linear Hydrologic System", J. Hydrol., 27: 319-329.
13. Muftuogla, R., 1991, "Monthly Runoff Generation by Non-Linear Models", J. Hydrol., 125: 277-291.
14. Ministry of Sciences and Technology, 2008, "Rainfall, Evaporation, Temperature and Daytime", Department of Meteorology.
15. Ministry of Water Resources, 2008, "Runoff Measurements", General Directorate of water Resources Management.
16. Kachroo, R.K. and Liang, G.C., 1992, "River Flow Forecasting", Part 2. Algebraic Development of Linear Modeling Techniques, J. Hydrol., 133:17-40.
17. Party, G.G. and Marino, M.A., 1983, "Non-Linear Runoff Modeling: Parameter Identification, Journal of Hydraulic Engineering ASCE, 109(6): 865-878.
18. Legates, D.R. and McCabe, G.J., 1999, "Evaluating the use of goodness-of-fit measures in hydrologic and hydroclimatic model validation, Water resources Research, 35(1): 233-241.
19. Beran, M., 1999, "Hydrograph Prediction-How Much Skill?", Hydrology of the Earth System Sciences, 3(2): 305-307.