Analysis of Mosul and Haditha Dam Flow Data

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ABSTRACT

The expansion in water projects implementations in Turkey and Syria becomes of great concern to the workers in the field of water resources management in Iraq. Such expansion with the absence of bi-lateral agreement between the three riparian countries of Tigris and Euphrates Rivers; Turkey, Syria and Iraq, is expected to lead to a substantially reduction of water inflow to the territories of Iraq. Accordingly, this study consists of two parts: first part is aiming to study the changes of the water inflow to the territory of Iraq, at Turkey and Syria borders, from 1953 to 2009; the results indicated that the annual mean inflow in Tigris River was decreased from 677 m^3/sec to 526 m^3/sec, after operating Turkey reservoirs, while in the Euphrates River the annual mean inflow was decreased from 1006 m^3/sec to 627m^3/sec after operating Syria and Turkey reservoirs. Second part is forecasting the monthly inflow and the water demand under the reduced inflow data. The results show that the future inflow of the Tigris River is expected to decrease to 57%, and reaches 301m^3/sec. The Mosul reservoir will be able to supply 64% only of the water requirements to the downstream. The share of Iraq from the inflow of the Euphrates River is expected to be 58%, therefore the future inflow will reach 290 m^3/sec. The Haditha reservoir will be able to supply 46% only of the water requirements to the downstream, due to reduced inflow at Iraqi border in the future.

Keywords: Time series; Reservoir operation; Tigris –Euphrates River; Dam; and Forecasting.

تحليل تدفق البيانات لسدي الموصل وحديثة

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الخلاصة

ان التوسع في انشاء مشاريع المياه في كل من تركيا وسوريا تقلق العاملين في حقل ادارة المياه في العراق حيث ليس هناك اتفاقية ثنائية بين الدول المتشاطئة (تركيا وسوريا والعراق) للاشتراك في مياه هذان النهران الدوليان دجلة والفرات مما سبب في انخفاض كميات المياه الواردة للعراق.

هذه الدراسة تتكون من جزءين :الجزء الاول هو دراسة التغير في كمية الواردات المائية القادمة للعراق عبر الحدود التركية والسورية للفترة من عام 1953 الى عام 2009. واشارت النتائج الى ان المعدل السنوي للوارد عند الحدود لنهر دجلة انخفض من 677 م^3/ ثا الى 526 م^3/ ثا بعد تشغيل السدود التركية. اما بالنسبة لنهر الفرات فأن المعدل السنوي للوارد عند الحدود انخفض من 1006 م^3/ ثا الى 627 م^3/ ثا بعد تشغيل السدود التركية والسورية. الجزء الثاني هو تخمين الوارد المائي الشهري والاحتياجات المائية في ضوء قلة الواردات المائية, حيث ان الوارد المستقبلي لنهر دجلة سيصل بنسبة 57% ليصل الوارد الى301م^3/ثا وان سد الموصل سيلبي 64% من الاحتياجات المائية لنهر دجلة. ان الوارد المستقبلي لنهر الفرات سيصل الى 290 م^3/ ثا على اساس ان الحصة المائية العراقية من نهر الفرات هي 58% وعليه سيلبي سد حديثة 46% من الاحتياج الكلي لنهر الفرات.

كلمات رئيسية : السلسلة الزمنية ; تشغيل الخزانات ; نهري دجلة والفرات ; سدود ; التخمين.

1. INTRODUCTION

The Tigris River is the second longest river in southwest Asia (1,840 km). The Tigris River rises in eastern Turkey near Lake Hazar and flows southeast to Iraqi borders at PaishKabur city, some of 400km from its source in Turkey **Kolars and Mitchell, 1991**. Through Iraq, numerous tributaries enter the lift bank of The Tigris River from the Zagros Mountains. Among these tributaries are the Greater Zab, the Lesser Zab, the Adhaim, and Diyala Rivers. While, the Euphrates River is one of the largest rivers of the Middle East; it originates in the mountainous areas of Turkey where up to 80% of the entire run off volume is formed, thenit crosses the territories of Turkey, Syria, and Iraq. The Euphrates River enters Iraq border at Hussaiba town. Many researchers have studied the Euphrates River and Tigris River basins and the Turkish Great Atatourk Project (GAP). **Kolars and Mitchell ,1991** introduced a chart for projected sequential depletion of the Euphrates River for the period 1990-2040. **Ishaq ,1998** studied the monthly optimal operation for the Iraqi water resources system for the periods (1962-1996)by a adopting an objective function to minimize the release and storage penalty. The result of optimization and simulation model indicated a deficiency in water supply for the periods (1974-1976) and (1989-1992).

El-obaidy ,2006 studied the effect of Turkish future projects implementation on Tigris River, this study consist of three parts; the first is to find synthetic time series. The second covers operating the existing and proposed reservoirs on Tigris River in Turkey. The third is to find the future expected water quality in accordance with the operation of the reservoirs. The optimum operational policies, from the Turkish point of view, show that the minimum flow irrigation requirements equal to 200 cumecs at the borders with Iraq.

Al-Bedyry ,2009 considered the Ilisu-Cizre reservoirs system as the case study, aiming at predict the effect of its optimal operation (from a Turkish point of view) on the flow of the Tigris River at the Turkish-Iraqi boarders, based on 51 years of real inflow data of the Tigris River recorded at Ilisu. The objectives were to test and remove a non- homogeneity from a historical monthly inflow data for Mosul, Dokan, and Haditha reservoir from 1952 to 2009, to analyze and forecast flow data of Tigris and Euphrates Rivers and to correct the monthly inflow coming to Iraqi borders, and the water demand according to reduced inflow data. The result of the study show that the annual flow at Iraqi borders will be equal to 9498MCM after operating Ilisu-Cizre reservoir.

2. THE STUDY AREA

The control system was divided into two sub systems. The first sub system consists of Mosul reservoir on Tigris River. The second sub system consists of Haditha reservoir on Euphrates River.

A- Mosul Dam is an embankment dam, it is the largest dam in Iraq. It is located on the Tigris River at the west of Ninawa governorate, approximately 50 km northwest of the town of Mosul, Iraq. The project is located approximately 65 km south from Iraq- Turkish border. The reservoir of the dam has been operated since 1986. it's a multi- purposes reservoir used mainly for flood control, supply water to Jazira irrigation projects and downstream river and generating hydro- power with a maximum capacity of 750MW **,Swiss Consultants, 1979**.

B- Haditha reservoir is located in the western part of Iraq about 140 Km from the Iraqi – Syrian border. The location of the reservoir is characterized by a dry and hot summer and a mild winter with low precipitation. It is an embankment reservoir, with a multi-purpose project intended for the control of the Euphrates River run off in order to meet the demands of irrigation, electrical power generation and flood control to a certain extent. The reservoir has been operated since 1986.

3. HYDROLOGICAL TIME SERIES

Hydrologic time series is defined as continuous sequential observations which is usually expressed as an average value over specific intervals of time such as mean daily, mean monthly, or mean annual flows. Hydrologic time series may consist of four components depending on the type of variable and the average time interval **Yevjevich ,1972**. In seasonal stream flow series four components exist as shown in Eq. (1):

$$Q_t = J_t + T_t + P_t + E_t \tag{1}$$

where:

Q_t is the time series value (actual data) at period t,
J_t is the jump component at period t,
T_t is the trend-cycle component at period t,
P_t is the periodic component at period t, and
E_t is the irregular (or remainder) component at period t.

For the test and removal of non-homogeneity, the suitability of the historical data must be checked. The homogeneity definition requires at least two conditions: -

1. The hydrological data series must not contain any systematic error.
2. All the hydrological conditions should be constant.

If these conditions are satisfied then the series may be considered as homogeneous. These two conditions imply that homogenous series should be free from trend and jump component respectively; therefore homogeneity should be insured at the beginning of the analysis by the detection and removal of jump and trend components.

1. ***Jump*** is a sudden considerable change in the parameters of historical data such as mean and standard deviation of the stream flow data. A sudden increase is called a positive jump, while a sudden decrease is called a negative jump.

2. ***Trend*** component is defined as a systematic and continuous change over an entire sample in any parameter of the series. The causes of trend are either sequential man-made changes within the catchments area, extensive urban or natural causes or inconsistency (systematic errors).

There are many methods to detect the existence of jump components, such as statistical tests (t-test, F-test, etc.), which can be used to check for any significant changes in means or standard deviations of two samples at the desired percent probability level of significant. If those tests indicate significance changes then it means that the two sub-samples are from different populations and a jump and/or trend components exist. Trend can also be detected by regression analysis and described mathematical by means of polynomial function. The most powerful method for testing homogeneity is suggested by **Yevjevich ,1972**. where the test for homogeneity is made by using the spilt-sample approach to ascertain whether or not the differences between the mean and standard deviation of the two sub-samples are significantly different from zero at the 95% confidence interval. This test requires that the sample be divided into two sub-samples.

4. ANALYSIS AND FORCASTING OF FLOW DATA

4.1 Mosul Dam

There is a gauge station at upstream Mosul dam on Tigris River. The mean monthly discharge data sample (1953-2009) is divided into two sub-samples; the first is (36) years long, (1953-1988), and the second is (21) years long, (1989-2009). **Fig. 1 and 2** show the annual means and standard deviations of the original time-series The solid line of those Figures represents the average of the annual means and standard deviations of the series. The results of Split – Sample Test of original data are shown in **Table 1**. From this table, the jump component exists in the annual mean and annual standard deviation.

The jump component on the data of the first sub-sample is removed by applying Eq. (2).

$$Y(j,t) = \frac{X(j,t) - 677}{588} * 460 + 526 \qquad (2)$$

where:

j,t = the annual and seasonal positions of observations, respectively. The overall mean and standard deviation of the last 21 years (1989-2009), were 460 m^3/sec and 526 m^3/sec, respectively.

The test is repeated using [Y (j, t)] series as the new first sub-sample, and the original second sub-sample, the result are shown in **Figs. (3) and (4)** for the annual means and standard deviations respectively. These Figures indicated the removal of the jump component from the hydrological data. Trend was detected by fitting linear regression equations for annual means and standard deviations against years. The correlation coefficients after removing the jump component are shown in **Figs. (1) and (2)** Those Figures show the existence of the trend component in the annual mean and annual standard deviation. The trend component on the data of the sample is removed by applying Eq. (3):

$$Y(j,t) = \frac{Y(j,t) + 540. - 0.5(i + j/12)}{478 - 0.6(i + j/12)} * 460 + 526 (3)$$

where:

j, t = the annual and seasonal positions of observations, respectively. The overall mean and standard deviation of the last 21 years (1989-2009), were 460 m^3/sec and 526 m^3/sec, respectively.

After that the test was repeated using [Y (j, t)] series as the new series for all sample, the results are shown in **Figs. (3) and (4)** for the annual means and standard deviations, respectively. Those figures show that the correlation coefficients are very small for linear trends, which indicates the absence of linear trend component. As shown in **Figs. (3) and (4)**, the slopes of these lines are mild enough to be attributed to sample fluctuations, which indicate that the trend component is removed from the hydrological data. The series now may be considered homogeneous, i.e. free from jump and trend components.

The Results of Split – Sample Test of data after removing the jump and trend components are shown in **Table 2**, which indicates that the jump and trend component does not exist anymore in the annual mean and annual standard deviation.

The expansion in water projects implementations in Turkey and Syria is reduces the water inflow to the territory of Iraq. Therefore, the inflow data under the developement of the construction of additional reservoir and increase of the irrigation projects since 1952, must be corrected to find the optimal monthly operation rules for Mosul, and Haditha reservoirs. The method used to correct the inflow data was by applying the annual flow at Iraqi border which is equal to 9498MCM **,Al-Bedyry, 2009**. The annual mean of 57 years were 16587 MCM. So, K (factor) from Eq. (4) is 57.3%, the future annual mean from Eq. (5) is 301.4 m^3/s and the future annual standard deviation from Eq. (6) is 264m^3/sec.

K (factor) = annual flow at Iraqi border / annual mean at this time in Iraqi (4)

New annual mean = Annual mean inflow after Removing the jump and trend K (factor)* (5)

New annual standard Deviation= Annual standard Deviation after Removing the jump and trend K (factor)* (6)

The corrected data inflow calculated by Eq. (7) as follow.

$$Y(j,t) = \frac{X(j,t) - 526}{461} * 264.15 + 301.39 \qquad (7)$$

where:
Y (j, t): new monthly inflow data (1953-2009).
X (j, t): old monthly inflow data (1953-2009).
The new corrected [Y (j, t)], as new series for all samples, are shown in **Figs. 5 and 6** for the annual means and standard deviations, respectively.

4.2 Haditha Dam

A gauge station is existed at Hesaiba town upstream of Haditha dam on the Euphrates River. A mean monthly discharge data sample (1953-2009) was divided into two sub-samples; the first is (20) years long (1953-1972), and the second is (37) years long (1973-2009). **Figs. 7 and 8** show the annual means and standard deviations of the original time-series. The solid line of those Figures represents the average of the annual means and standard deviations of the series. **Figs. 7 and 8** show is the presence of jump in the annual flow data of Haditha dam.
The results of Split–Sample Test of original data are shown in **Table 1**. From this table it is clear that the jump component exists in the annual mean and annual standard deviation.
The jump component on the data of the first sub-sample was removed by applying Eq. (8):

$$Y(j,t) = \frac{X(j,t) - 1006}{867} * 241 + 627 \qquad (8)$$

where
j,t = the annual and the seasonal positions of observations, respectively, the number 241 m^3/sec and 627 m^3/sec are the overall mean and standard deviation of the last 37 years (1973-2009), respectively.

The test repeated using [Y (j, t)] series as the new first sub-sample, and the original series as the second sub-sample, as shown in **Figs. 9 and 10** for the annual means and standard deviations, respectively. Those Figures indicate that the jump component was removed from the hydrological data.

Trend was detected by mean of regression analysis. That was made by fitting linear regression equations for annual means and standard deviations against years. The correlation coefficients after removing the jump component are shown **in Figs. 7 and 8.** Those figures show that the trend component was existed in the annual mean and annual standard deviation. The trend component was removed by applying Eq. (9):

$$Y(j,t) = \frac{Y(j,t) + 695.3 - 2.3(i + j/12)}{258.4 - 0.6(i + j/12)} * 241 + 627 \quad (9)$$

where:

j, t = the annual and seasonal positions of observations, respectively, the numbers 241 m^3/sec and 627 m^3/sec are the overall mean and standard deviation of last 27 years (1973-2009), respectively.

The test repeated using [Y(j,t)] series as the new series for all samples, the result for the annual means and standard deviations are shown in **Figs. 9 and 10**. Those figures show that the correlation coefficients were very small for linear trends, which indicates the absence of linear trend component. As also shown in **Figs. 9 and 10**, the slopes of these lines are mild enough to be attributed to sample fluctuations, which indicate that the trend component was removed from the hydrological data. Accordingly, the series can be considered homogeneous, i.e. free from jump and trend components.

The results of Split–Sample Test of the data after removing the Jump component are shown in **Table 2**. This table show that the jump and trend components do not exist in the annual mean and annual standard deviation.

Considering that the total inflow of Euphrates River at the Turkish-Syrian border as 500m 3/sec, and the share of Iraq from this inflow is equal to 58% (**Ministry of Water Resources)**, then

*Annual flow at Iraqi border =500 * 0.58 =290m^3/sec, and*

Annual Standard Deviation =134.0 m^3/sec.

$$Y(j,t) = \frac{X(j,t) - 626.4}{241.1} * 134.0 + 290.0 \quad (10)$$

Accordingly, the correct inflow data is calculated by Eq. (10).

where:

Y (j, t): new monthly inflow data (1953-2009).

X (j, t): old monthly inflow data (1953-2009).

The new corrected [Y (j, t)], as new series for all samples, are shown in **Figs. 11 and 12** for the annual means and standard deviations, respectively.

5.RESULTS AND CONCLUSIONS

- The analysis of the 57 years (for the period 1953-2009) of historical monthly stream flow downstream Mosul , and Haditha reservoirs indicate significant changes occurred through the period of the record, which means that the series is not homogenous. There was jump and trend components exist in the data and indicated by the mean and the standard deviation. The annual inflow at further of Tigris River will be decreased to 57%, meaning reduction from (526 m^3/sec to 301m^3/sec).

- The annual inflow at further of Euphrates River will be decreased to 58%, meaning reduction from (626 m^3/sec to 290m^3/sec).
  - Mosul reservoir can supply 64% of the water requirements downstream with an actual value of 469 m^3/sec, while the adopted value is 301 m^3/sec due to the expected reduction of the inflow at Iraqi border in the future.
  - Haditha reservoir Mosul reservoir can supply 76.3%, of the water requirements downstream with actual value of 723m^3/sec, while the adopted value is 551m^3/sec at current study and will supply 46.3% with actual value of 551 m^3/sec where the adopted value is 255m^3/sec due to future inflow reduction at Iraqi border.

6. RECOMMENDATIONS

- This study recommended that statistical analysis should be done from time to time to monitor the drops in the annual inflow due to the operation of the new dams and irrigation projects in Turkey and Syria to improve the quality of the data in order to be taken into consideration in the operation of Iraqi reservoirs system.
- The operating rules for Iraqi reservoirs must be reviewed to account for the inflows reduction.
- New researches that focus on the operation of Turkish and Syrian future projects implementation on Tigris, Euphrates, Grater Zab and Less Zab River will be required to determine the future inflow and salinity at Iraqi borders.
- Optimization of the operation of Mosul, Haditha, Dokan, Hemreen, Derbendikhan and Al-Tharthar reservoirs after operating new reservoirs in Turkey and Syria.

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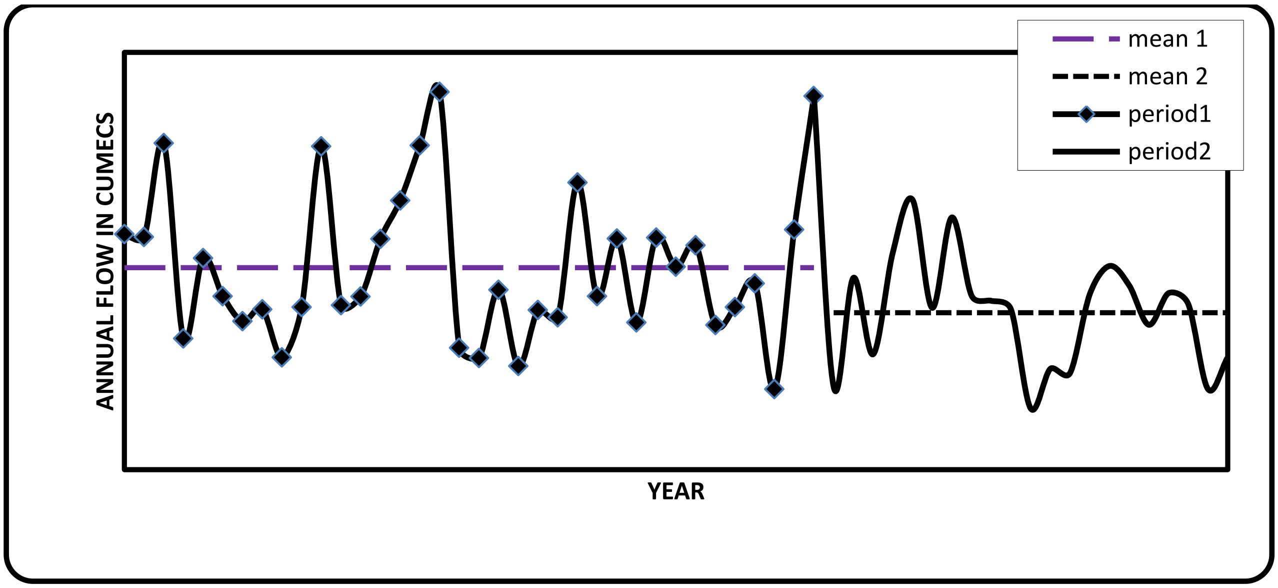

Figure 1. Annual flow upstream Mosul Dam (m^3/sec).

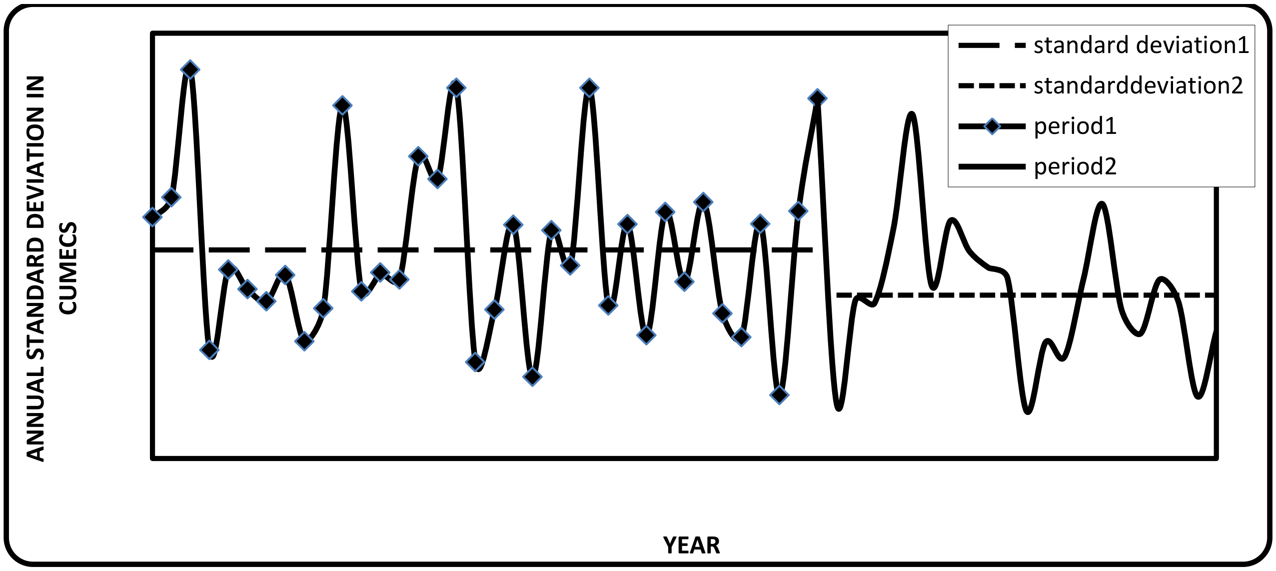

Figure 2. Annual standard deviation of the flow upstream Mosul Dam.

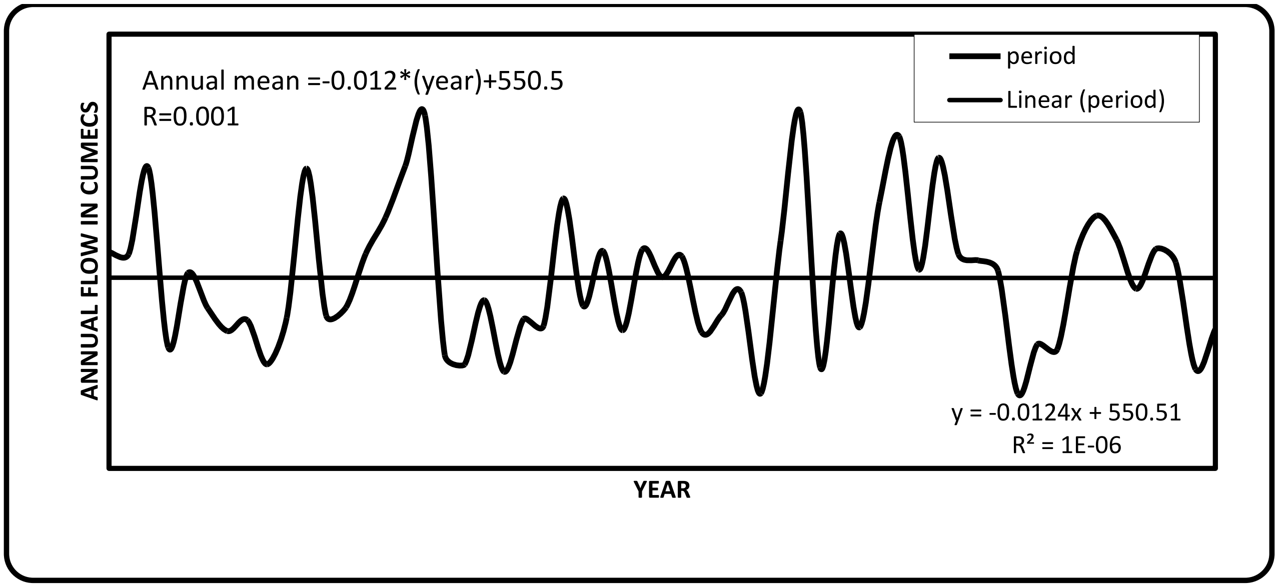

Figure 3. Annual flow at upstream Mosul Dam (m^3/sec), (After removing the jump and trend components).

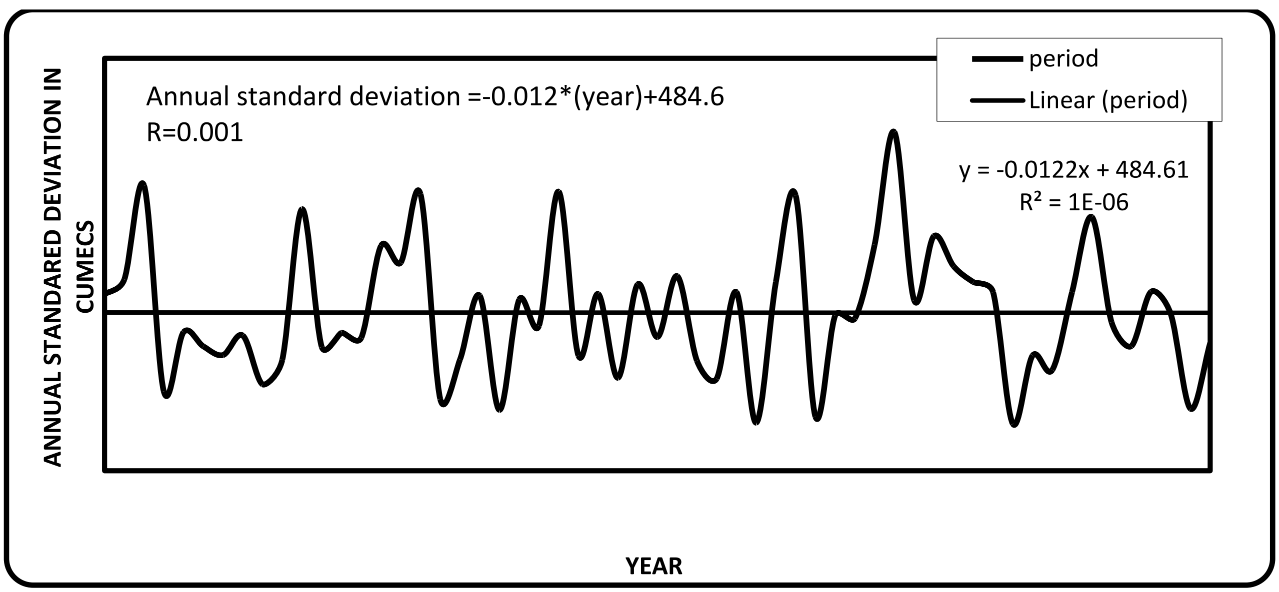

Figure 4. Annual standard deviation of the flow at upstream Mosul dam (m^3/sec). (After removing the jump and trend components).

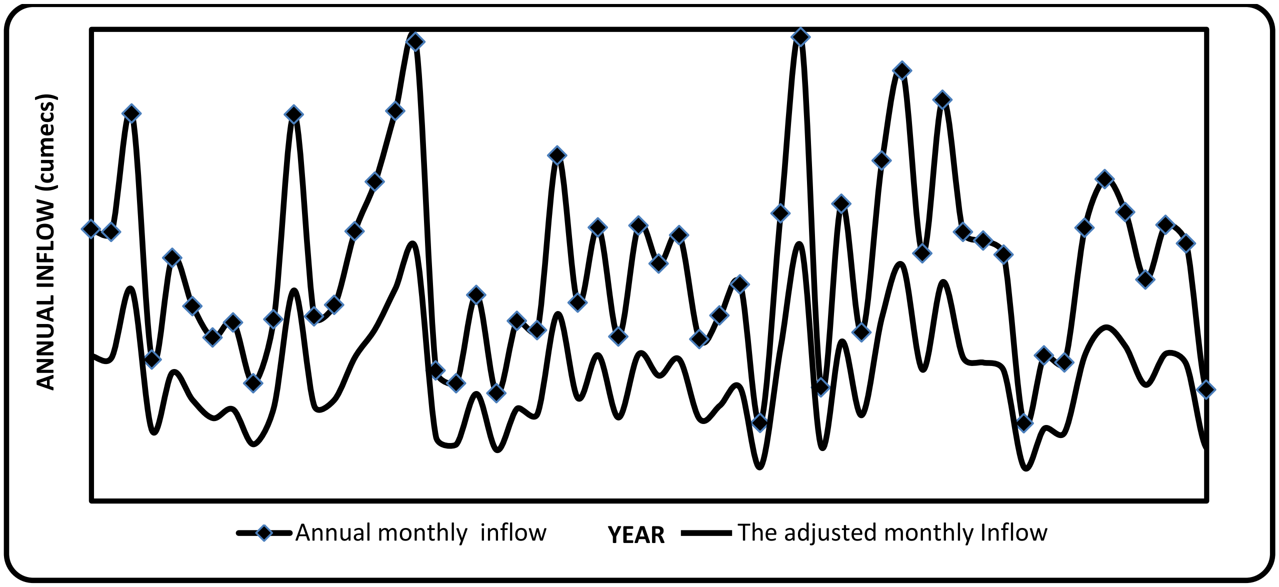

Figure 5. The adjusted monthly inflow (m^3/sec) of Tigris River up stream Mosul dam.

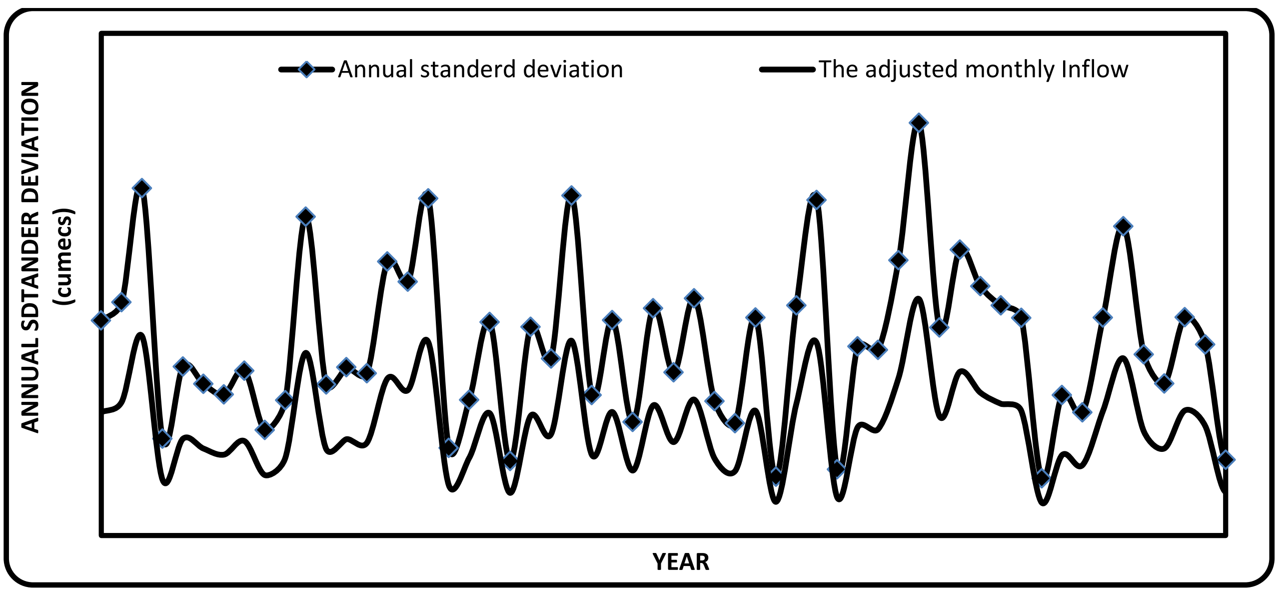

Figure 6. The adjusted monthly standard deviation (m^3/sec) of Tigris River up stream Mosul dam.

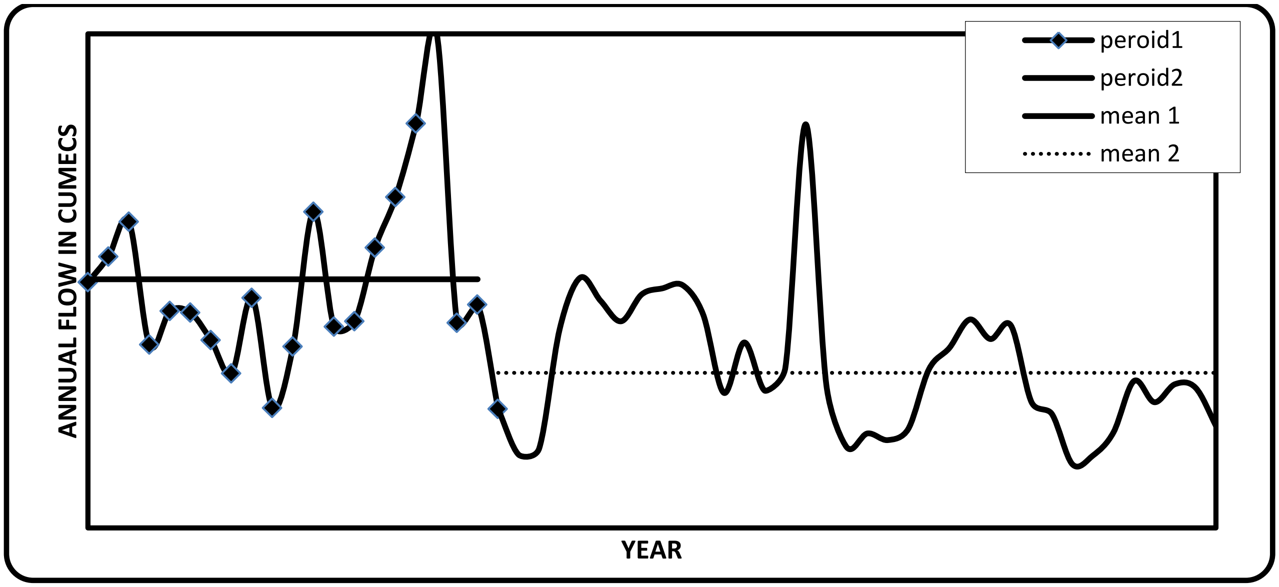

Figure 7. Annual flow at Haditha dam (m^3/sec).

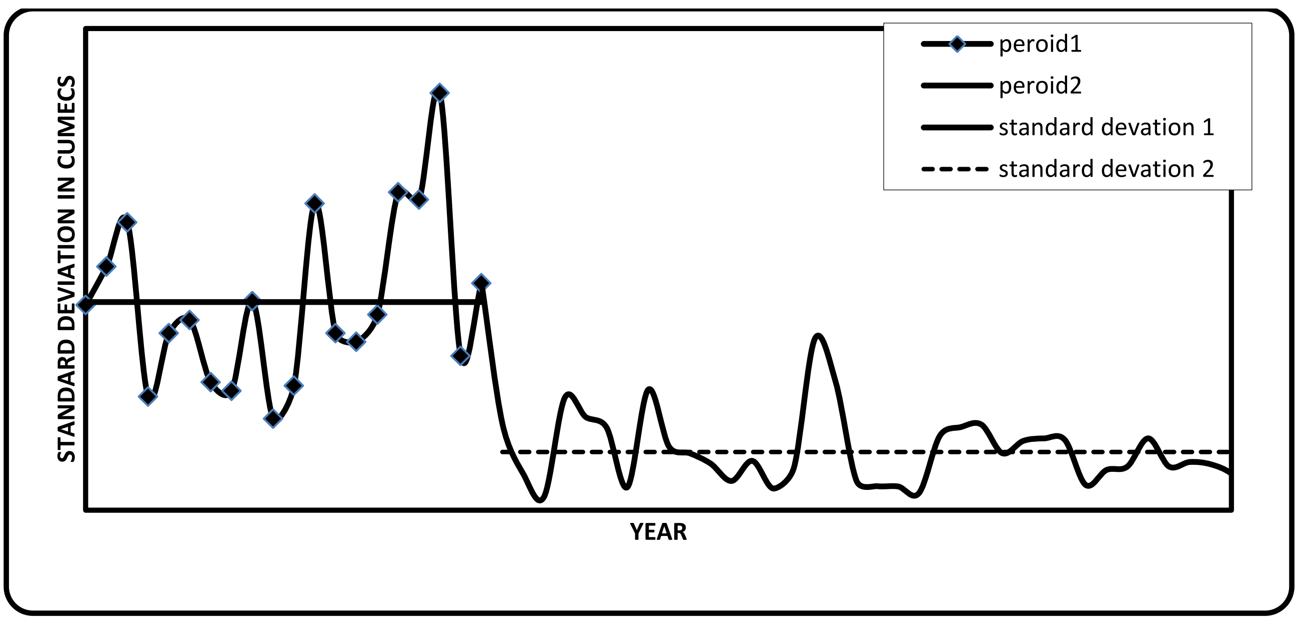

Figure 8. Annual standard deviation of the flow at Haditha dam (m^3/sec).

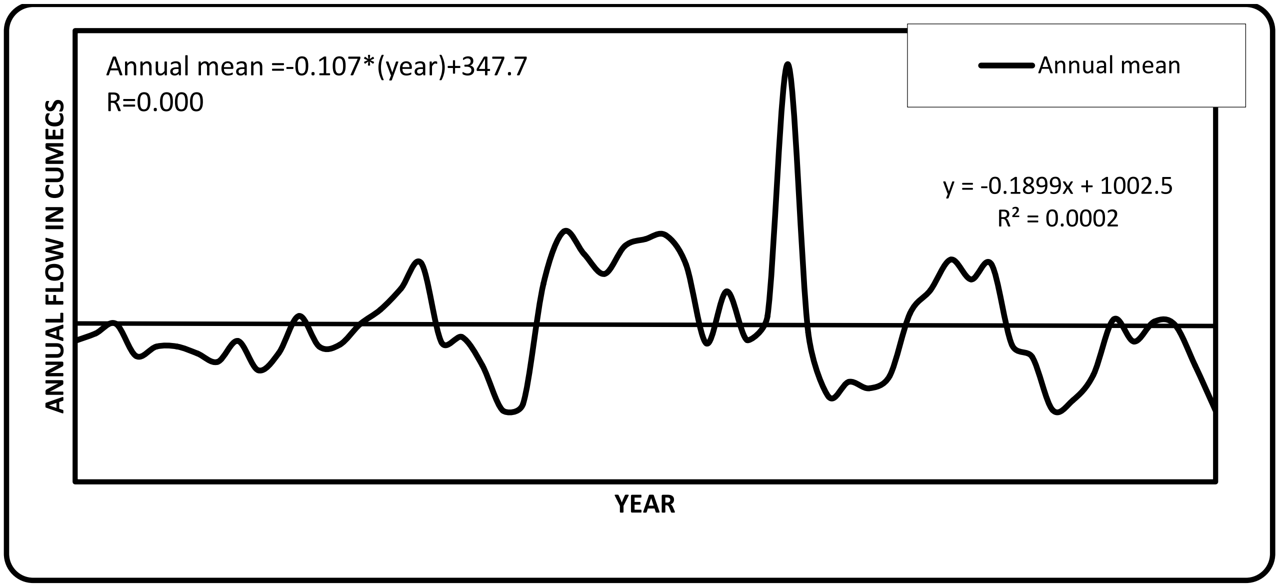

Figure 9. Annual flow at Haditha Dam (m^3/sec), (After removing the jump and trend components).

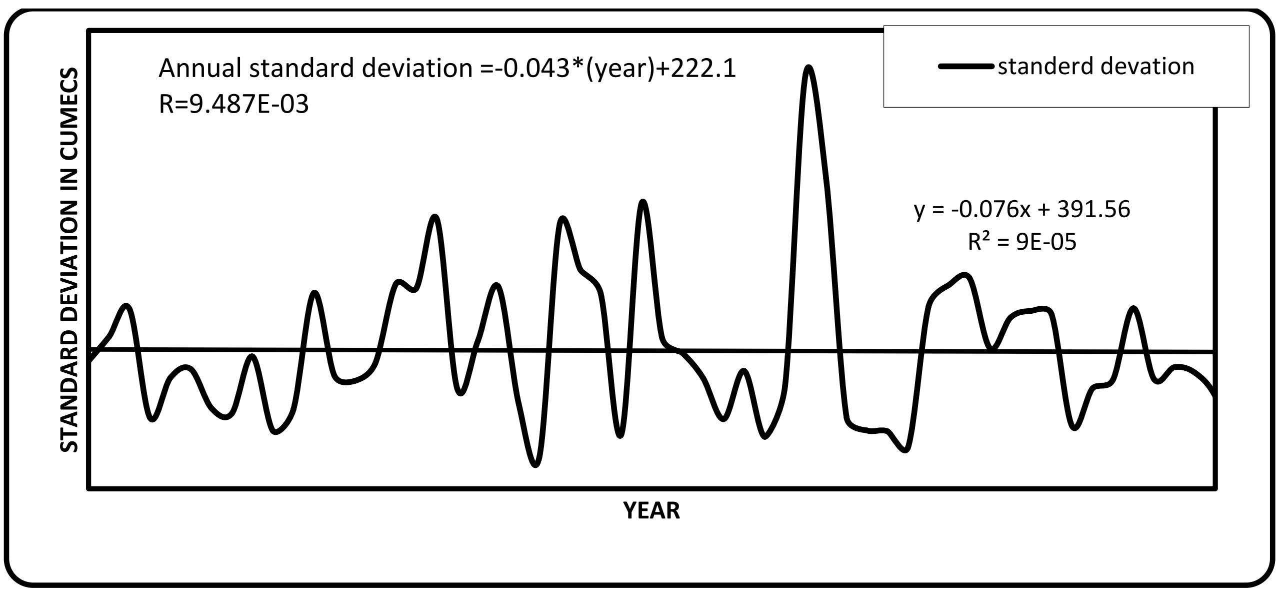

Figure 10. Annual standard deviation of the flow at Haditha dam (m^3/sec), (After removing the jump and trend components).

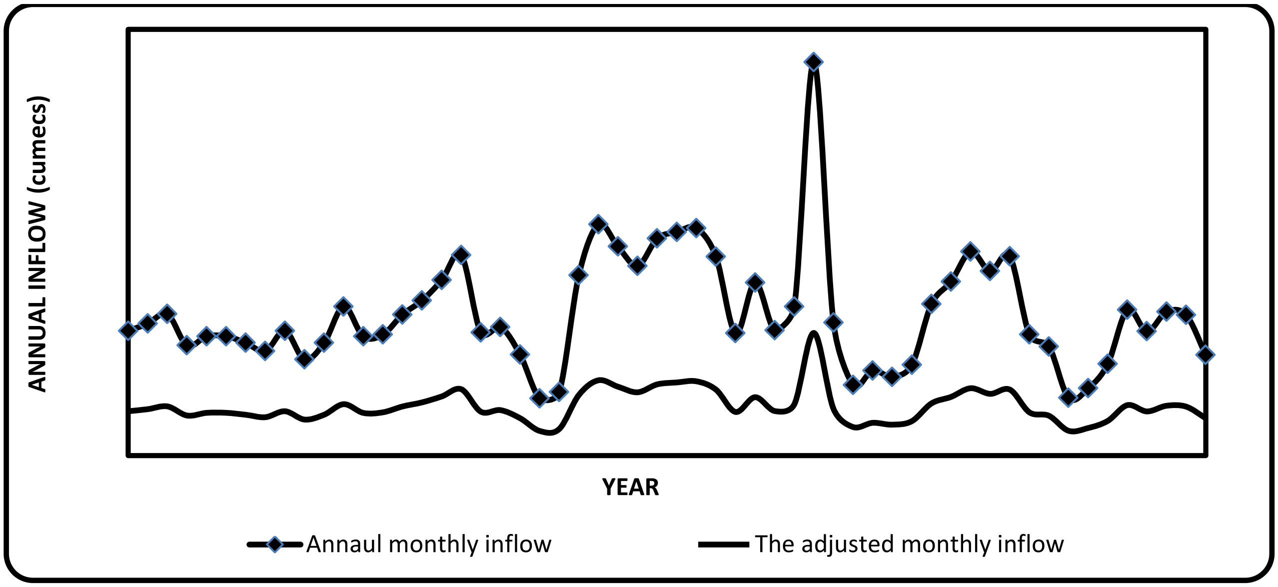

Figure 11. The adjusted monthly inflow (m^3/sec) of Euphrates River up stream Haditha dam.

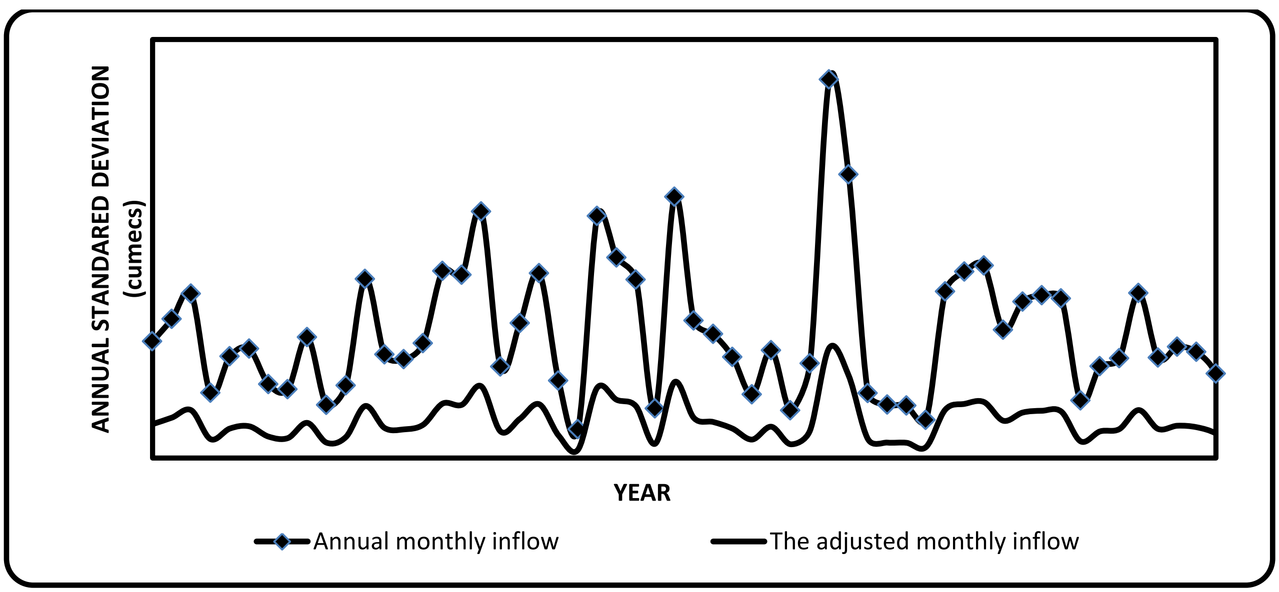

Figure 12. The adjusted monthly standard deviation of the flow at Haditha dam (m^3/sec).

Table 1. Results test of original data.

Reservoir	Statistical Parameters	Annual Mean m^3/sec	Annual Standard Deviation m^3/sec	
Mosul	No. of Years	36	36	1st. Periods (19531988)
	Average	677.46	588.44	
	Standard Deviation	252.83	240.10	
	No. of Years	21	21	2nd. Periods(19892009)
	Average	526.44	460.76	
	Standard Deviation	186.76	193.79	
	t-value	2.381	2.072	
	t-table	2.002	2.002	
	Jump Component	Exist	Exist	
Haditha	No. of Years	20	20	1st. Periods (19531988)
	Average	1006.57	867.32	
	Standard Deviation	357.44	340.75	
	No. of Years	37	37	2nd. Periods(19892009)
	Average	627.62	241.47	
	Standard Deviation	285.24	145.14	
	t-value	2.508	4.375	
	t-table	2.002	2.002	
	Jump Component	Exist	Exist	

Table 2. Results test of data after removing the jump and trend component.

Reservoir	Statistical Parameters	Annual Mean m^3/sec	Annual Standard Deviation m^3/sec	
Mosul	No. of Years	36	36	1st. Periods (19531988)
	Average	521.20	454.33	
	Standard Deviation	195.20	185.40	
	No. of Years	21	21	2nd. Periods(19892009)
	Average	534.82	471.11	
	Standard Deviation	189.90	196.84	
	t-value	-0.256	-0.322	
	t-table	2.002	2.002	
	Jump Component	Not Exist	Not Exist	
Haditha	No. of Years	36	36	1st. Periods (19531988)
	Average	502.00	191.42	
	Standard Deviation	119.45	125.28	
	No. of Years	21	21	2nd. Periods(19892009)
	Average	515.05	262.51	
	Standard Deviation	217.92	127.45	
	t-value	-0.293	-2.054	
	t-table	2.002	2.002	
	Jump Component	Not Exist	Not Exist	