Genetic Algorithm Optimization Model for Central Marches Restoration Flows with Different Water Quality Scenarios

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ABSTRACT:

A Genetic Algorithm optimization model is used in this study to find the optimum flow values of the Tigris river branches near Ammara city, which their water is to be used for central marshes restoration after mixing in Maissan River. These tributaries are Al-Areed, Al-Bittera and Al-Majar Al-Kabeer Rivers. The aim of this model is to enhance the water quality in Maissan River, hence provide acceptable water quality for marsh restoration. The model is applied for different water quality change scenarios ,i.e. , 10%,20% increase in EC,TDS and BOD. The model output are the optimum flow values for the three rivers while, the input data are monthly flows(1994-2011),monthly water requirements and water quality parameters (EC, TDS, BOD, DO and pH).The objective function adopted in the optimization model is in a form the sum of difference in each of the 5 water quality parameters, resulting from the mixing equation of the waters of the rivers, from the accepted limits of these parameters , weighted by a penalty factor assigned for each water quality parameter according to its importance. The adopted acceptable limits are 1500,1000, 6,4 and 7, while the penalty factors are 1,0.8,0.8,0.8,and 0.2 for EC,TDS,BOD,DO,and pH respectively. The constraints adopted on the decision variables which the monthly flows of the three rivers are those that provide the monthly demands downstream each river, and not exceed a maximum monthly flow limits. The maximum flow limits adopted are for three flow cases, wet, average and dry years. For each flow case three scenarios for the monthly water quality parameters were adopted , the average values(scenario 1),the 10% increase in EC,TDS, and BOD (Scenario 2),and the 20% increase in these three water quality parameters (Scenario 3). Hence nine cases are adopted and for each an optimum monthly flows are found for each river. The genetic optimization model adopt a variable number of population of 100 to 1000 in a step of 100,0.8 and 0.2 cross over and mutation rates, and three iterations to reach the stable optimum solutions. The results indicates that the flow analysis shows a significant decrease in the flow values of the three rives after year 2000,hence, the flow values for the period of (1994-1999), are excluded and the only used values are those for (2000-2011). The estimated monthly demands exhibits low variation. The observed optimum monthly flow values decrease in general as the case flow changed from wet to normal and dry cases. The change in Scenarios from S1 to S2 and S3 , do not necessarily increase all the required optimum monthly flow values. The obtained minimum objective functions do not exhibits a certain trend with the change in the flow cases and/or the change in the scenarios.

KEY WORDS: Genetic Algorithm, Optimization, Water Quality Parameters, Electrical Conductivity, Total Dissolved Solids, BioChemical Oxygen Demand

نموذج الجينات الوراثية لايجاد الاطلاقات المطلوبة للجريان لانعاش الاهوار المركزية باستخدام عدة صيغ لنوعية المياه

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لقد تم استخدام نموذج الجينات الوراثية في هذا البحث لحساب التصاريف المثلى لتفرعات نهر دجلة قرب مدينة العمارة حيث تستخدم مياهها لأعادة انعاش الاهوار المركزية وهذه التفرعات هي انهر العريض والبتيره والمجر الكبير بعد خلطها في مياه نهر ميسان. الهدف من هذا النموذج هو الحصول على افضل نوعية مياه لغرض الانعاش للاهوار المركزية.ولغرض الحصول على امثل التصاريف لهذه الانهر تم بناء برنامج حاسبة بلغة (MATLAB) حيث ان النتائج المستخرجة من البرنامج تمثل قيم التصاريف المثلى للانهر الثلاث وان المدخلات للبرنامج هي التصاريف للفترة من (1994-2011) و معدل الاستهلاك المائي الشهري ومعاملات نوعية المياه وهي (EC, TDS, BOD, DO and pH).

تهدف الدالة الهدفية (Objective Function) المستخدمة في نموذج البرمجة لتقليل المجموع الكلي لانحرافات معاملات نوعية المياه عن قيمها المسموح بها. الاولوية التي تم التعامل بها مع معاملات نوعية المياه تم تمثيلها باوزان معينة حسب اهمية كل معامل القيم للاوزان المستخدمة هي (1,0.8,0.8,0.8,0.2) لكل من (EC,TDS,BOD,DO,pH) على التوالي وذلك حسب اهمية كل معامل. اما معدل التزاوج و معدل المراوحة فهما (0.8, 0.2) على التوالي.

اما حجم المجتمع المطلوب فقد تم ايجاده بطريقة المحاولة والخطأ ابتداأ من (100) وحتى (1000) وبخطوة قدرها 100) حيث اعطت القيمة الأ خيرة حلا مستقرا وبعدد معاودات قدره (3).

استخدم النموذج ثلاث حالات لقيم معاملات نوعية المياه وثلاث حالات من الجريان (سنوات رطبة وطبيعية وجافة) لكل نهر. اما المحددات للتصاريف فقد كهنت قيم التصاريف الشهرية حسب نوع السنة المائية كحدود عليا وقيم المتطلبات الشهرية كقيم دنيا. تم تشغيل النموذج على الحالات التسعة ثلاث حالات للجريان كما ذكر سابقا رطبة و طبيعية وجافة ولكل حالة جريان ثلاث حالات لقيم نوعية المياه الحالة (S1) استخدمت فيها معدلات معايير نوعية المياه المقاسة والحالتين (S2) و(S3) باستخدام زيادة في قيم (EC,TDS, BOD) قدرها (10% و 20%) على التوالي. اضهرت النتائج لتحليل الجريان وجود انخفاض واضح بعد سنة (2000) عليه تم اعتماد التصاريف للفترة (2000-2011) فقط. كما وجد بان قيم المتطلبات الشهرية المحسوبة ذات تغاير قليل. اما قيم التصاريف الشهرية المثلى فقد وجد بانها تقل بشكل عام كلما تغيرت حالة الجريان من رطبة الى طبيعية و جافة. اما التغاير في قيم الجريان الامثل مع تغير حالة نوعية المياه من (S1) الى و (S2, S3) فقد وجد بانه ليس من الضروري وجود زيادة في قيمها. اما دالة الهدف الدنيا التي وجدت لكل الحالات التسعة اضهرت عدم وجود تدرج واضح في قيمها مع تغير حالة الجريان وحالة نوعية المياه.

INTRODUCTION:

The past activities in the Iraqi Marshes region had destroyed the environment and the nature of these marshes. These activities are either, establishing agriculture projects, holding ground roads , redistributing the rural settlement, and diverting water from those marshes by constructing dykes and canals. The central marsh is one of the largest marshes of the Mesopotamian. It consists of interconnected small marshes. The central marshes are bounded by Tigris river to the east and the Euphrates river to the south. The central marshes are roughly located between Nasiriyah, Maimona, Qalat Saleh and Al-Qurna Cities, and cover of about 3000 square Kilometers during flood season. This area reduced to 600 square Kilometers during normal season. The main sources of the water for the central marshes are the Tigris river tributaries within Ammara governorate. These tributaries are Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers. Figure (1) and (2) shows the Mesopotamian marshes before and after the drying process respectively, (Al-Suhiaili and Hraizeو 2006).

Al-Badri and Artin (1972) had studied the salinity problem in Tigris and Euphrates rivers and Thurthar lake. They concluded that at future an expected increase in the salinity levels due to upstream increasing water use and disposal and due to the Turkish activites proposed a case which observed later. Buras (1972) had proposed an optimum management of water resources for Iraqi marshes for a better water quality.. Firas (1989) had pointed out the importance of environmental considerations in optimization models for Derbindikhan reservoir. Mussab(1998) had presented an optimization model for Saddam and Dokan reservoir and their effect on Tigris River water Quality.Hassan(2001) had pointed out the environmental effects of marshes drying process.

Nicholson et. al,(2002), and Clarck et. al,(2001) had conducted an environmental study of Iraqi marshes and pointed out the negative effect of the drying process. Iraq Foundation (2003) had studied the scientific bases for marshes restoration in Iraq. Richardson and Hussain (2005) had conducted an ecological study for the Iraqi marshes and pointed out the importance of water quality to the eco-system of these marshes. Farhan (2005) had reported the importance of water quality for marshes restoration.

The construction of Maissan River with dykes along its sides was the main action performed by the past regime for conducting a drying process for the central marshes.. The alignment of this river prevents water of the Tigris three tributaries Al-Areed, Al-Bittera and Al-Majar Al-Kabeer from entering the central marshes. The proposed restoration process is to remove or break these dykes to allow the water to enter the marshes. Therefore the control of this river water quality is important for this restoration process. The problem of the high salinity level of the dried soil of the marshes left after the drying process is an important issue; hence, the proper control of the salinity and other environmental parameters will improve the water quality in Maissan river and will have an important role on the quality of the water used for the restoration process.

Since at the upstream side of each of the three rivers Al- Areed, Al-Bittera and Al-Majar Al-Kabeer there exists a regulator , which can control the released flow. An optimization model could be adopted to find these optimum releases to get the best water quality in Maissan river, and then the best water quality of the water entering the marshes for restoration. In this research , a proposed optimization model was used for this purpose. This model is a modified one of that proposed optimization model used by Al-Suhaili and Hraze (2006). The modifications made herein from this model are the use of additional flow and water quality measured data of these rivers (2006-2011), in addition to the original set used in the former model (1994-2005). This modification impose changes in the constraints used for the optimization process. Moreover the proposed solution of the new model is the use of Genetic Algorithm instead of the general search method. Furthermore the estimation of monthly demands along the mentioned three rivers was also extended to the new period added. Moreover the model analysis was extended for three scenarios (S1: using obtained average monthly water quality parameters as Electrical Conductivity EC, Total Dissolved Solids TDS,Biochemical oxygen Demand BOD, Dissolved Oxygen DO, and pH.), and Scenarios S2 and S3 with 10% and 20% increase in EC,TDS,and BOD, respectively. The adopted acceptable limits are 1500,1000, 6,4 and 7, while the penalty factors are 1,0.8,0.8,0.8,and 0.2 for EC,TDS,BOD,DO,and pH respectively

The Proposed Optimization Model:

The proposed optimization model is to minimize the water quality function represented by the following function:

$$Min(f) = \Sigma \sum_{k=1}^{nk} \left[\frac{\sum_{k=1}^{3} \overline{Q}_{i,j} C_{i,j,k}}{\sum_{i=1}^{3} \overline{Q}} - C_k \right] * P_k \tag{1}$$

Where:

$$\overline{Q}_{i,j} = Q_{i,j} - D_{i,j} \geq 0, otherwise Qi, j = 0, \tag{2}$$

Subject to the following constraints:

$$D_{i,j} \leq Q_{i,j} \leq Q_{i,j\max}$$

During wet years

And

$$D_{i,j} \leq Q_{i,j} \leq Q_{i,j\min}$$

During dry years

And

$$D_{i,j} \leq Q_{i,j} \leq Q_{i,jave.}$$

During normal years

Where:

C_k = Acceptable limit of water quality parameter k.

p_k = Relative penalty weight for the k quality parameter.

For the upper limit acceptable concentration of the water quality parameter p_k will be positive and:

$$P_k = \begin{bmatrix} greaterthan 0, lessorequal 1 \\ o \end{bmatrix} \begin{matrix} C^*_{k,j} \geq 0 \\ C^*_{k,j} < 0 \end{matrix}$$

For the lower limit acceptable water quality parameter p_k will be negative,and:

$$P_k = \begin{bmatrix} greaterthan 0, lessorequal 1 \\ 0 \end{bmatrix} \begin{matrix} C^*_{k,j} \leq 0 \\ C^*_{k,j} > 0 \end{matrix}$$

$$C^*_k = \frac{\sum_{i=1}^{m} Q_{i,j} C_{i,j}}{\sum_{i=1}^{m} Q_i C_i} - C_k \tag{3}$$

J= 1, 2, 3 ….12, represent the month starting from October and ending at September, respectively, as the water year of Tigris river.

K= Subscript for water quality parameters type k

i=1, 2, and 3, which represent the rivers, Al-Areed, Al-Bittera, and Al-Majar Al Kabeer rivers respectively.

Qi, j: are the optimum water release from the river i, at the month j.

Di, j: are the demand along the river i, at month j for the area located between the upstream of regulator to the location where the river i, enters Maissan river.

Qi, j min: are the minimum flow from river i at month j(Dry Year).

Qi, j max: are the maximum flow from river i at month j(Wet Year).

Qi, j ave: are the average flow from river i at month j(Normal Year).

Ci, j, k: Is the average values of the river i, at month j of the k water quality parameter.

The objective function was adopted by assuming complete mixing of water at Maissan river. The above formulated optimization model requires the monthly flow values of the three rivers, the average EC, TDS, BOD, DO and pH and the monthly demands for each area downstream each river. These are estimated from the observed flows and water quality parameters for the three rivers for (1994-2011).

PREPERATION OF THE DATA REQUIRED FOR THE PTIMIZATION MODEL:

Flow Data Analysis:

The data collected were the monthly flow data in $m^3/\sec$ for a record of (18) year long (1994-2011) for the three rivers. Examination of those data indicates a remarkable decrease in the available water for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers as shown in figure (3). Hence, the flow data for the first six years were excluded and the analysis were performed on the flow of the most resent years (2000-2011), for the three rivers.

If we, consider the flow data as normally distributed with mean value μ and standard deviation σ, so the data can be divide into three categories for each river.

I. Normal year: represents the average of flow values that fall within the interval $(\mu+\sigma/2, \mu-\sigma/2)$.

II. Dry year: represents the average of flow values below the value $(\mu-\sigma/2)$.

III. Wet year: represents the average of flow values above the value $(\mu+\sigma/2)$.

Table (1) shows the average flow values available in the selected three rivers in $m^3/\sec$,for wet,normal and dry years.

Demand Analysis:

The demand data were collected from different authorities that had conducted demand calculations during the most recent years (2000-2011). These data were collected from the demand sheets recorded by the general management of water resources, and the office of environmental of Maissan governorate (unpublished records). Table (2) shows the estimated demand values for the three rivers.

WATER QUALITY DATA USED IN THE OPTIMIZATION MODEL:

The available records of the water quality data for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers are inadequate for the purpose of the proposed optimization model. Hence, a water quality-testing program was conducted in some selected points to get the required additional data. The criteria of the selection adopted for those points is for each river two points were selected at the upstream side (downstream of the regulator existing on the river), while the other point is at the downstream side of the river, just before its outfall to Maissan river. The water quality parameters gathered are TDS, EC, pH, DO, BOD water temperature and air temperature. Tables (3), (4) and (5) show the measured and estimated average monthly values of (EC, TDS, BOD, DO and pH) for Al-Areed, Al-Bittera and AL-Majar Al-Kabeer rivers respectively.

APPLICATION OF THE OPTIMIZATION MODEL:

In this study, a MATLAB program was used to find the optimum flow values for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers using genetic algorithm optimization .The optimum flow values and the objective function are obtained for the three scenarios and the three flow cases wet , normal and dry years. Tables(3,4, and 5) show the water quality parameters for scenario S1,while tables (6,7, and 8) show these values for scenario S2. For scenario S3 these values are shown in tables(9,10, and 11). Hence the total cases analyzed are 9 cases S1(Wet, Normal, and Dry),S2 (Wet, Normal, and Dry), and S3 (Wet,Normal, and Dry).

RESULTS AND DISCUSSION:

For the optimization process a MATLAB code is written. The adopted cross over and mutation rates are 0.8 and 0.2 respectively. The number of population is found by trial and error procedure until obtaining a stable optimum solution. It is increased from 100 to 1000 in a step of 100, at 1000 a stable solution is found .

Table(12) shows the optimum monthly flow values for the three rivers for Scenarios S1 for the three flow cases. Figures (4,5, and 6) show these values with the adopted average water quality parameters and the estimated flows and demands. It is shown that in general as the flow case changes from wet to normal and dry year the optimum flow decreases.

Table(13) shows the optimum monthly flow values for the three rivers for Scenarios S2 for the three rivers with the three flow cases. Figures (7,8, and 9) show these values with the adopted 10% increase in water quality parameters (EC,TDS, and BOD)and the estimated flows and demands. It is shown that in general as the flow case changes from wet to normal and dry year the optimum flow decreases.

Table(14) shows the optimum monthly flow values for the three rivers for Scenarios S2 for the three flow cases. Figures (10,11, and 12) show these values with the adopted 20% increase in water quality parameters (EC,TDS, and BOD) and the estimated flows and demands. It is shown that in general as the flow case changes from wet to normal and dry year the optimum flow decreases.

Table(15) shows the obtained minimum objective function for the 9 cases adopted in the analysis. It is shown that the values do not exhibit a certain trend with the changes of flow case or the change in the scenario.

Figure(13) shows the comparison between the obtained optimum flow values for each of the three rivers, for Scenario S1, for wet, normal and dry years . It is found that the dry case flow gives the minimum flow values, while the maximum values are obtained for the wet year flow cases, the normal flow case are in between the wet and dry values ,however some few values exceed the corresponding values for the wet case flow.

Figures(14 and 15) show the comparison between the obtained optimum flow values for each of the three rivers, for Scenarios S2, and S3 for wet, normal and dry years . Similar observation can be deduced as those for Figure (13).

Figure(16) shows the comparison between the obtained optimum flow values for each of the three rivers, for a wet year and the different scenarios. It is observed that for scenario S3 the optimum flow are almost the highest, however for few monthly optimum flow it becomes lower than that for S2 and/or S1 flow values.

Figures(17 and 18) show the comparison between the obtained optimum flow values for each of the three rivers, for a normal and a dry year respectively and each for the different three scenarios. Similar observations can be deduced as those observed from Figure(16).

CONCLUSIONS:

1. The analysis of the (12) years for the period (1994-2005), of historical monthly stream flow for the three rivers indicates significant changes occurred through the period of record which means that the series is not homogeneous. Hence, the values for the flow for the period(1994-1999) are excluded from the analysis and those used are for the period of (2000-2011).

2. The demand analysis indicates low variation with little increase in summer months.

3. The Genetic algorithm optimization model that use a 0.8 and 0.2 cross over and a mutation rates, required a minimum population of 1000 to obtain a stable optimum solution.

4. In general as the flow case changes from wet to normal and dry year , the optimum flow values required decreases, however for few months sometimes the optimum flow for normal year exceeds the corresponding value for the wet year. This conclusion is true for all of the three scenarios analyzed.

5. The comparison between the optimum monthly flow values for different scenarios for a given case flow , indicates in general the highest flow are for S3,however it is not always the case since so many values exhibits high flow values for S2 and/or S1.

6. The minimum observed objective function obtained for the 9 cases analyzed exhibits no certain trends with the change in case flow or with the change in the water quality scenario.

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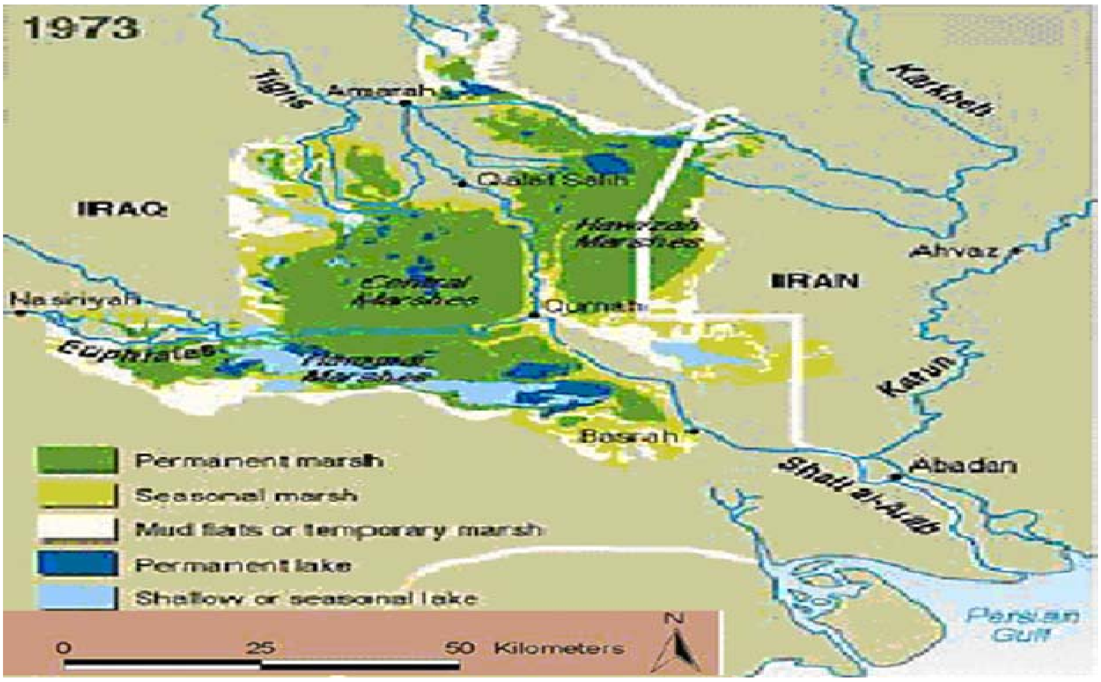


Figure (1) The Mesopotamian Marshes before Drying (UNEP, 2001).

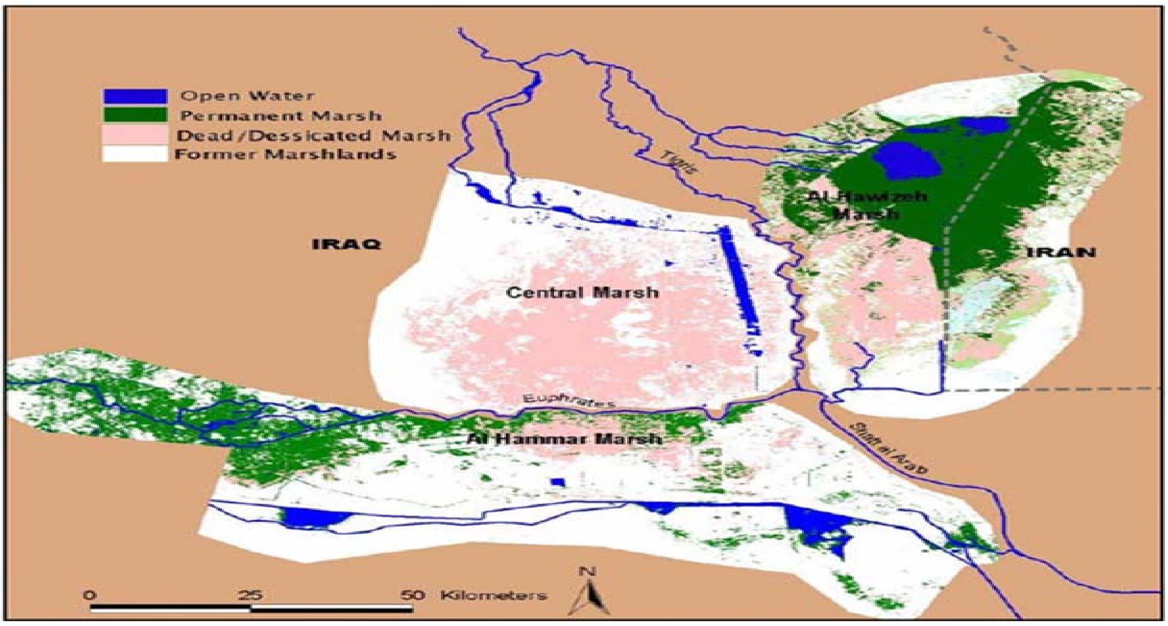


Figure (2) The Mesopotamian Marshes after Drying (UNEP, 2001).

Table (1) Average monthly Flow Values in m^3/sec Available in the Selected Three rivers.(2000-2011)

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Al-Areed river												
Wet	18	16	21	14	16	19	35	25	28	24	25	16
norm	11	11	14	11	11	12	16	12	12	13	14	12
Dry	7	6	10	7	6	8	11	7	9	9	8	9
Al-Bittera river												
Wet	28	44	45	41	45	59	130	58	32	33	41	33
norm	15	22	22	16	23	22	33	26	20	26	31	25
Dry	10	12	14	10	12	9	11	10	9	10	11	12
Al-Majar Al-Kabeer river												
Wet	28	32	34	32	28	31	32	31	30	28	27	24
norm	24	23	28	28	27	25	28	24	25	20	22	19
Dry	16	16	22	19	17	18	20	14	18	12	19	13

Table (2) Estimated Monthly Demand Values in m^3/sec Upstream of Maissan river.

month river	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Al-Areed	6	5	7	5	5	6	8	5	7	7	7	7
Al-Bittera	8	9	11	9	9	8	10	8	9	8	8	8
Al-Majar Al-Kabeer	10	10	9	9	9	10	10	10	10	10	10	9

Table (3) Average values of (EC, TDS, BOD, DO and pH) for Al-Areed river (downstream)(2000-2011) Scenario S1.

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1650	1498	1498	1487	1456	1466	1489	1350	1440	1895	1560	*1950*
TDS	910	1115	1002	1046	1067	1115	1076	1185	1096	1022	1089	*886*
BOD	6.5	5.3	5.2	4.9	4.8	4.7	4.6	4.1	3.9	5.0	4.2	*5.8*
DO	6	5.0	5.2	5.8	5.0	5.8	5.4	4.8	5.2	5.3	6.1	*6*
pH	*8*	*7.8*	*7.9*	*7.7*	*7.8*	*7.9*	*7.8*	*8*	*7.8*	*7.6*	*7.8*	*8*

Table (4) Average values of (EC, TDS, BOD, DO and pH) for Al-Bittera river (downstream) (2000-2011) Scenario S1..

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1500	1808	1780	1757	1780	1830	1710	1750	1870	1920	2200	*1600*
TDS	1020	1140	1143	1140	1150	1145	1140	1150	1200	1200	1250	*990*
BOD	5	3.9	3.9	4	3.6	4	3.9	4	4.5	3.8	3.7	*5*
DO	5.7	6.5	6	5.8	6	6.5	6.5	5.3	5.1	5.4	5.5	*5.4*
pH	*8*	*8.1*	*8.1*	*8.2*	*8.1*	*8.1*	*8.1*	*7.9*	*8.3*	*8.1*	*8.1*	*6*

Table (5) Average values of (EC, TDS, BOD, DO and pH) for Al-Majar Al-Kabeer river (downstream).(2000-2011) Scenario S1.

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1560	1470	1550	1570	1350	1780	1700	1450	1600	1500	1500	*1800*
TDS	980	800	1020	950	1010	800	850	800	850	690	1000	*800*
BOD	5.2	5.9	6	6.2	6.1	6	6.2	6.3	5.9	6.7	5.2	*6.1*
DO	6	6	6.8	6.3	6	6.2	5.5	5.7	5.8	5.1	5.1	*5.7*
pH	*8.1*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*7.8*	*8.1*	*8.1*	*8.1*	*8*

Table (6) Proposed values of (EC, TDS, BOD, DO and pH) for Al-Areed river (downstream) for Senario (2)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
EC	1815	1647.8	1637.9	1635.7	1601.6	1612.6	1637.9	1485	1584	2084.5	1716	2145
TDS	1001	1226.5	1102.2	1150.6	1173.7	1226.5	1183.6	1303.5	1205.6	1124.2	1197.9	974.6
BOD	7.15	5.83	5.72	5.39	5.28	5.17	5.06	4.51	4.29	5.5	4.62	6.38
DO	6	5.0	5.2	5.8	5.0	5.8	5.4	4.8	5.2	5.3	6.1	6
pH	8	7.8	7.9	7.7	7.8	7.9	7.8	8	7.8	7.6	7.8	8

Table (7) Proposed values of (EC, TDS, BOD, DO and pH) for Al-Bittera river (downstream) for Senario (2)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1650	1988.8	1958	1932.7	1958	2013	1881	1925	2057	2112	2420	1760
TDS	1122	1254	1257.3	1254	1265	1259.5	1254	1265	1320	1320	1375	1089
BOD	5.5	4.29	4.29	4.4	3.96	4.4	4.29	4.4	4.95	4.18	4.07	5.5
DO	5.7	6.5	6	5.8	6	6.5	6.5	5.3	5.1	5.4	5.5	*5.4*
pH	*8*	*8.1*	*8.1*	*8.2*	*8.1*	*8.1*	*8.1*	*7.9*	*8.3*	*8.1*	*8.1*	*6*

Table (8) Average values of (EC, TDS, BOD, DO and pH) for Al-Majar Al-Kabeer river (downstream) Senario (2)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1716	1617	1705	1727	1485	1958	1870	1595	1760	1650	1650	1980
TDS	1078	880	1122	1045	1111	880	935	880	935	759	1100	880
BOD	5.72	6.49	6.6	6.82	6.71	6.6	6.82	6.93	6.49	7.37	5.72	6.71
DO	6	6	6.8	6.3	6	6.2	5.5	5.7	5.8	5.1	5.1	*5.7*
pH	*8.1*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*7.8*	*8.1*	*8.1*	*8.1*	*8*

Table (9) Proposed values of (EC, TDS, BOD, DO and pH) for Al-Areed river (downstream) for Senario (3)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1980	1797.6	1786.8	1784.4	1747.2	1759.2	1786.8	1620	1728	2274	1872	2340
TDS	1092	1338	1202.4	1255.2	1280.4	1338	1291.2	1422	1315.2	1226.4	1306.8	1063.2
BOD	7.8	6.36	6.24	5.88	5.76	5.64	5.52	4.92	4.68	6	5.04	6.96
DO	6	5.0	5.2	5.8	5.0	5.8	5.4	4.8	5.2	5.3	6.1	*6*
pH	*8*	*7.8*	*7.9*	*7.7*	*7.8*	*7.9*	*7.8*	*8*	*7.8*	*7.6*	*7.8*	*8*

Table (10) Average values of (EC, TDS, BOD, DO and pH) for Al-Bittera river (downstream) For Senario (3)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1800	2169.6	2136	2108.4	2136	2196	2052	2100	2244	2304	2640	1920
TDS	1224	1368	1371.6	1368	1380	1374	1368	1380	1440	1440	1500	1188
BOD	6	4.68	4.68	4.8	4.32	4.8	4.68	4.8	5.4	4.56	4.44	6
DO	5.7	6.5	6	5.8	6	6.5	6.5	5.3	5.1	5.4	5.5	*5.4*
pH	*8*	*8.1*	*8.1*	*8.2*	*8.1*	*8.1*	*8.1*	*7.9*	*8.3*	*8.1*	*8.1*	*6*

Table (11) Average values of (EC, TDS, BOD, DO and pH) for Al-Majar Al-Kabeer river (downstream) Scenario (3)

month par.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	*Sep*
EC	1872	1764	1860	1884	1620	2136	2040	1740	1920	1800	1800	2160
TDS	1176	960	1224	1140	1212	960	1020	960	1020	828	1200	960
BOD	6.24	7.08	7.2	7.44	7.32	7.2	7.44	7.56	7.08	8.04	6.24	7.32
DO	6	6	6.8	6.3	6	6.2	5.5	5.7	5.8	5.1	5.1	*5.7*
pH	*8.1*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*8.2*	*7.8*	*8.1*	*8.1*	*8.1*	*8*

Table (12) Optimum Flow Values for (wet, normal and dry years) for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers (Scenario 1).

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet years												
Areed	9.4	10.6	20.8	8.5	12.5	6,5	21.1	23.3	23.2	9.5	23.5	12
Bittera	12.8	18.3	16.5	19.5	18.2	16.9	30.6	43.53	24	11.2	31	14.5
Majar	14	30	30	29	16.5	25.9	22.4	30.2	29.2	18.9	21.8	19.6
Normal years												
Areed	7	9.3	13.6	7.8	6.3	10.8	15.3	10.2	7.3	7.7	10.4	9
Bittera	11.2	15.3	12.1	10.3	17.6	20.5	28.6	18.1	10.7	14	14.8	12.3
Majar	20	20	26	26	20	20	20	21	23	17	22	18
Dry years												
Areed	6.1	5.7	8.8	5	5.8	7.8	9.1	6.1	8.9	8.9	7.2	7.8
Bittera	9.6	9.2	12.5	9.7	11.5	8.7	10.7	8.4	9	8.8	9.9	9.2
Majar	15.6	14	16.9	12	15.7	14.4	16.8	12.5	15.1	10.9	11.7	12.6

Table (13) Optimum Flow Values for (wet, normal and dry years) for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers (Scenario 2).

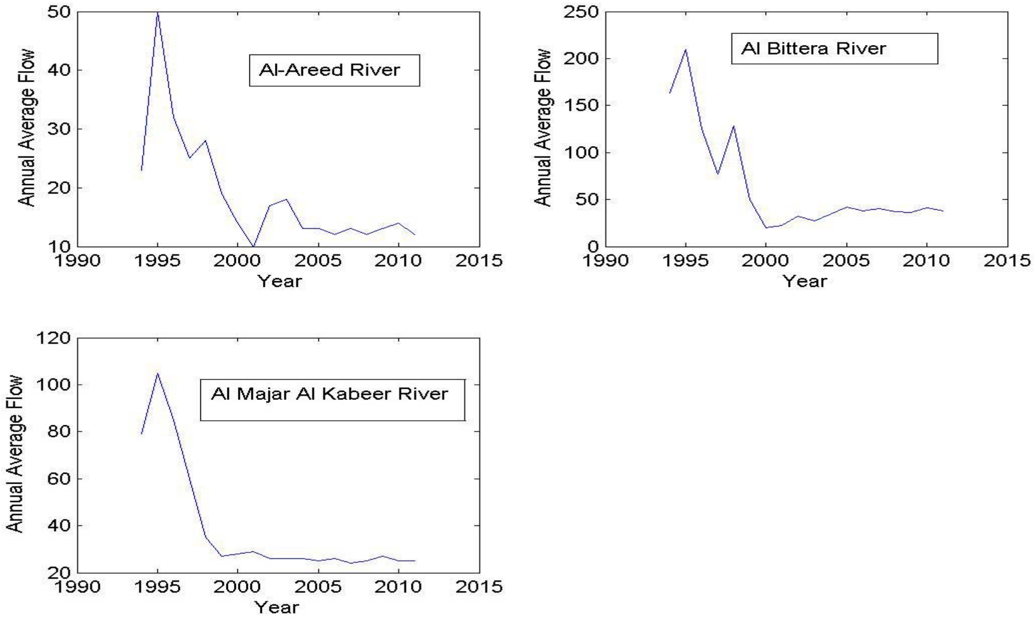
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet years												
Areed	6	12.5	18.6	11.2	11.9	8.8	30.9	9.4	25.1	24	16.8	10.8
Bittera	16.3	41.4	40	14.8	36	15.5	102.8	17.5	24.5	21.1	32.8	32.1
Majar	26.6	31.5	25.1	21.3	21	25.2	26.1	14.8	29.4	19	17.9	32.1
Normal years												
Areed	7.2	8.7	9	6.9	8.2	7.7	15.7	8.3	11.8	10	10.6	7.8
Bittera	11.7	13.5	14.6	12.9	12.7	15	31.2	22.5	15.4	10.1	9	19
Majar	17.8	22.6	17.4	21.3	17.5	15.3	20.8	22.5	12.5	14.9	21.8	16.1
Dry years												
Areed	6.1	5.8	8.8	6.6	5.9	7.1	10.7	5.8	8.2	7.5	8	7
Bittera	8.6	9.6	13.9	9.8	9.2	8	10.8	9.8	9	8	9.5	9.6
Majar	12.9	12.6	18.6	14.4	10.6	11.8	19.5	11.2	10.9	11.8	13.8	11.7

Table (14) Optimum Flow Values for (wet, normal and dry years) for Al-Areed, Al-Bittera and Al-Majar Al-Kabeer rivers (Scenario 3).

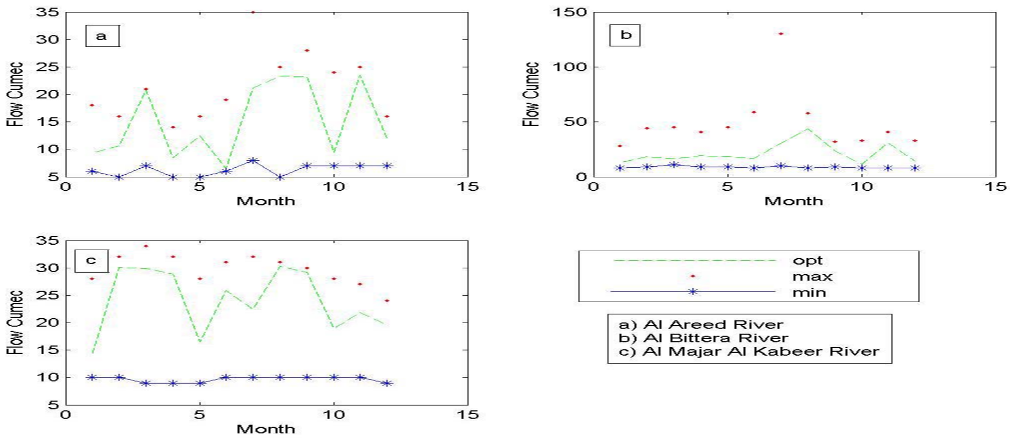
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wet years												
Areed	17.2	14.6	20.7	13.6	15.7	10	28.2	16.5	27.9	16.9	23.9	13.4
Bittera	21	22	29	18.7	32.6	19.3	82.3	23.3	15.6	12.4	32.8	10.4
Majar	27.9	21.2	19.5	31.5	13.6	30.6	32	17.5	19.7	27	26.5	12.9
Normal years												
Areed	10.3	10.3	9.7	5.9	7.3	8.8	12.1	7.9	11.3	12.2	13	11.7
Bittera	8.2	18.5	16.5	15	12.8	16.7	21.8	14.9	11.9	20.2	16.4	14.5
Majar	23.1	16.8	16	18.7	14.5	19	27.3	17.6	21.2	17.5	14	18.2
Dry years												
Areed	7	5.5	9.6	5.8	5	8	10.5	5.6	8.4	8.8	7.8	7.6
Bittera	9.2	11.4	13.7	9.4	11.2	8.7	10.9	8.9	9	9.3	9.5	9.3
Majar	16	15	12.2	11	14.3	10.6	15.5	11	13	12.9	12.8	12.4

Table (15) Minimum Obtained Objective Function Values for all of the Scenarios and Flow Cases.

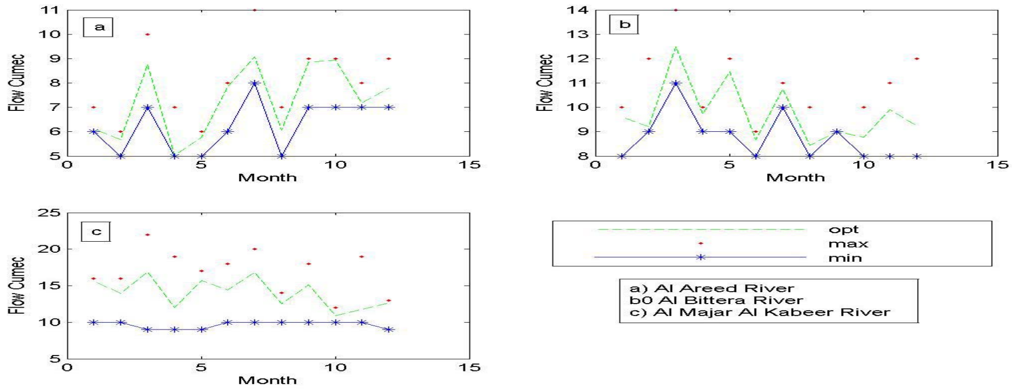
Scenario	Wet	Normal	Dry
S1	74.96	77.30	76.19
S2	79.57	78.20	79.82
S3	85.87	76.86	76.88



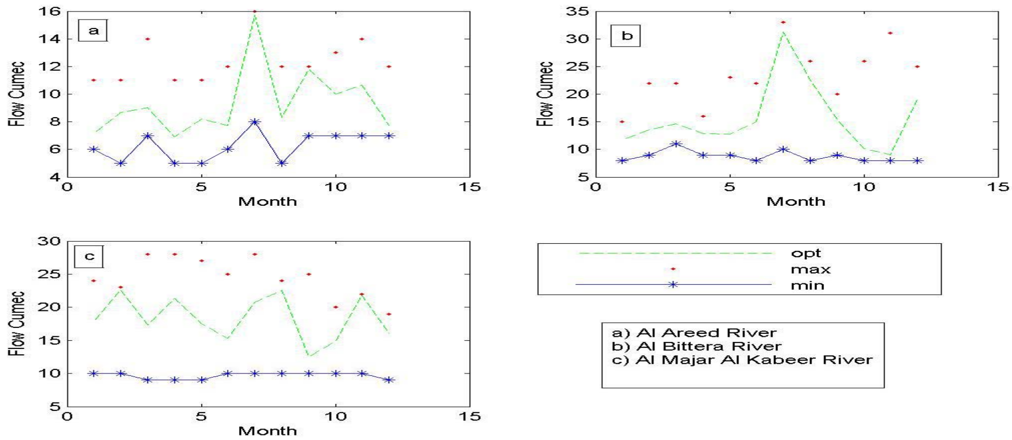
Fig(3) Average Annual Flow for the Three Rivers, Al Areed, Al Bittera ,and Al Majar Al kabeer (1994-2011).



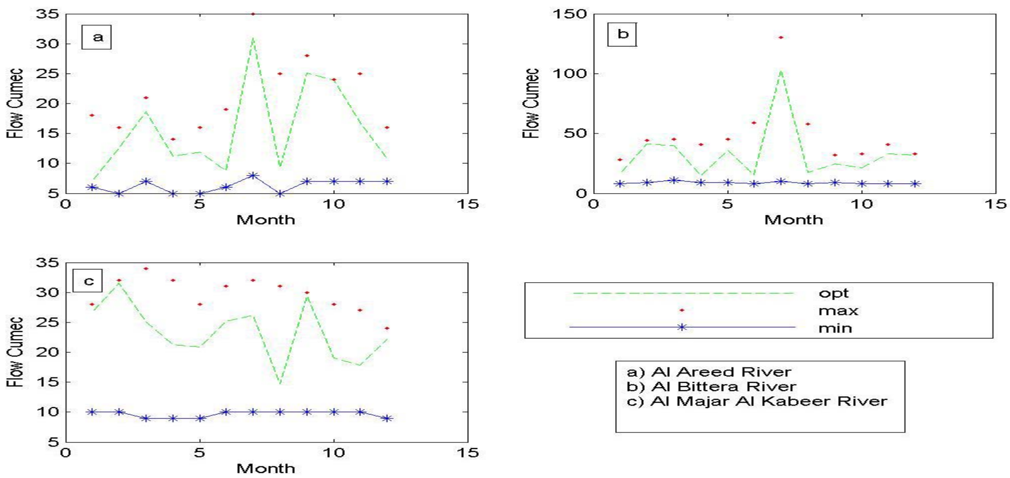
Fig(4) Optimum Monthly Flow Values for Scenario (S1), Average Water Quality, for a Wet year.



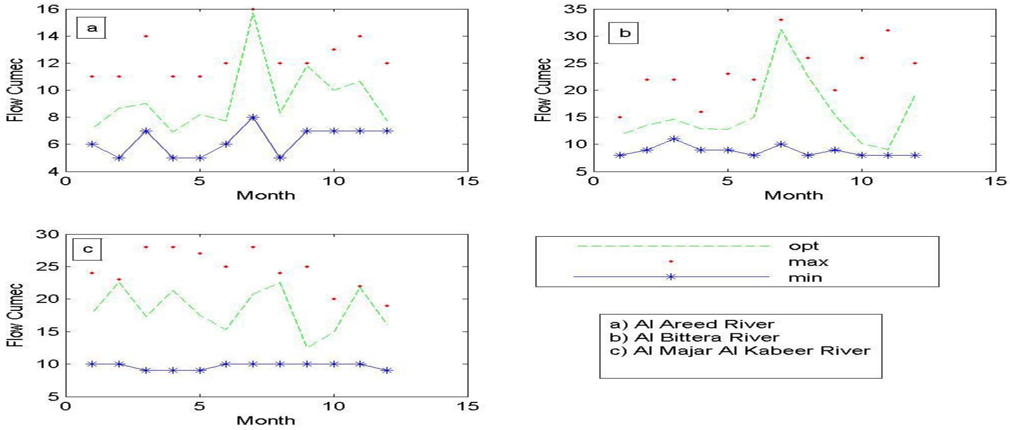
Fig(5) Optimum Monthly Flow Values for Scenario (S1), Average Water Quality, for a Normal Year.



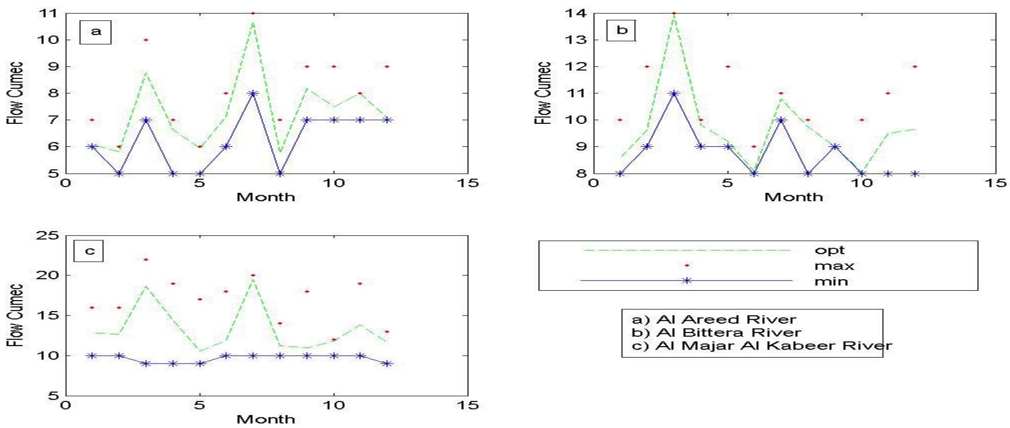
Fig(6) Optimum Monthly Flow Values for Scenario (S1), Average Water Quality, for a Dry Year.



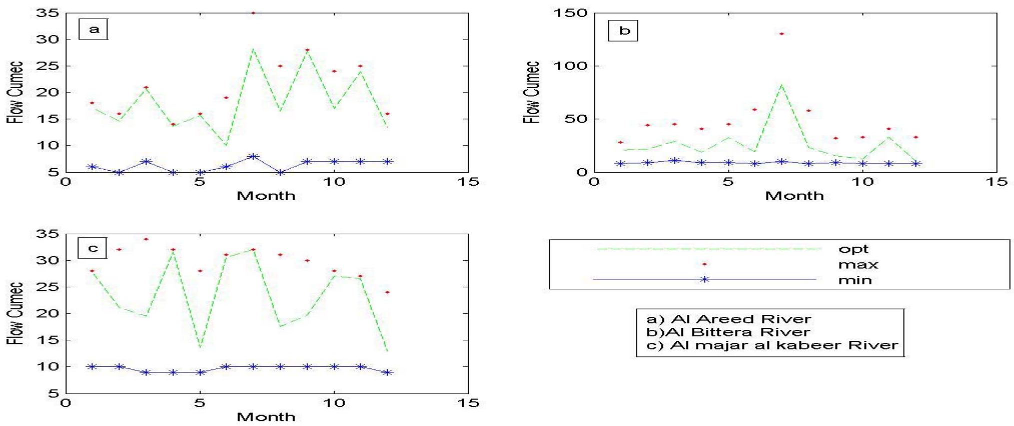
Fig(7) Optimum Monthly Flow Values for Scenario (S2), 10% Increase in EC,TDS,and BOD Values, for a Wet Year.



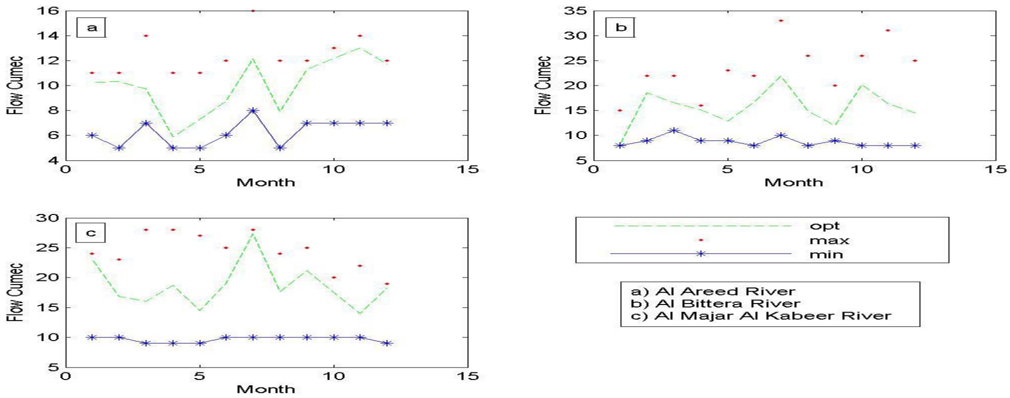
Fig(8) Optimum Monthly Flow Values for Scenario (S2), 10% Increase in EC,TDS,and BOD Values, for a Normal Year.



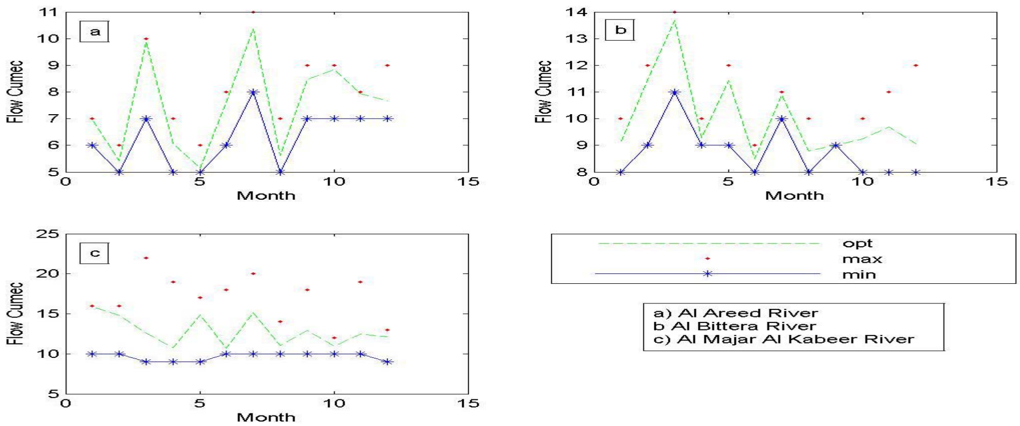
Fig(9) Optimum Monthly Flow Values for Scenario (S2), 10% Increase in EC,TDS,and BOD Values, for a Dry Year.



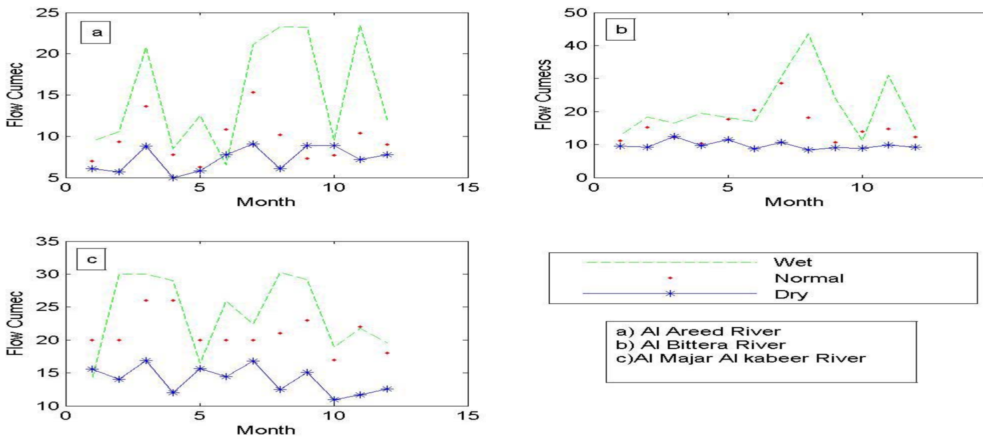
Fig(10) Optimum Monthly Flow Values for Scenario (S3), 20% Increase in EC,TDS,and BOD Values, for a Wet Year.



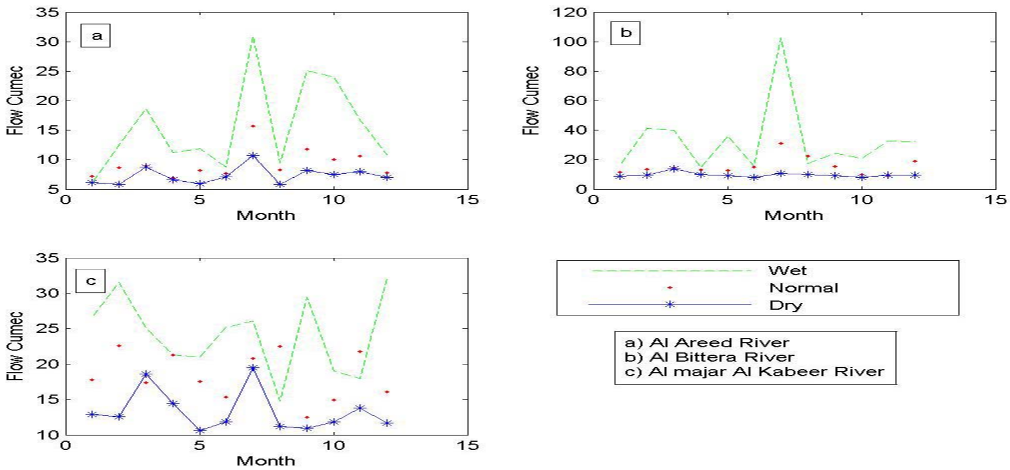
Fig(11) Optimum Monthly Flow Values for Scenario (S3), 20% Increase in EC,TDS,and BOD Values, for a Normal Year.



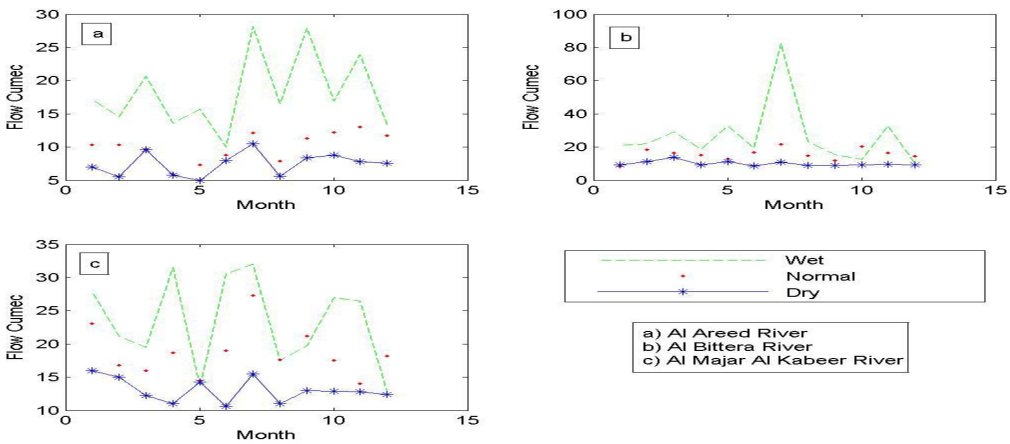
Fig(12) Optimum Monthly Flow Values for Scenario (S3), 20% Increase in EC,TDS,and BOD Values, for a Dry Year.



Fig(13) Optimum Flow for the Three Rivers for Wet , Normal and Dry Years, for Scenario S1.



Fig(14) Optimum Flow for the Three Rivers for Wet , Normal and Dry Years,for Scenario S2.



Fig(15) Optimum Flow for the Three Rivers for Wet , Normal and Dry Years, for Scenario S3.

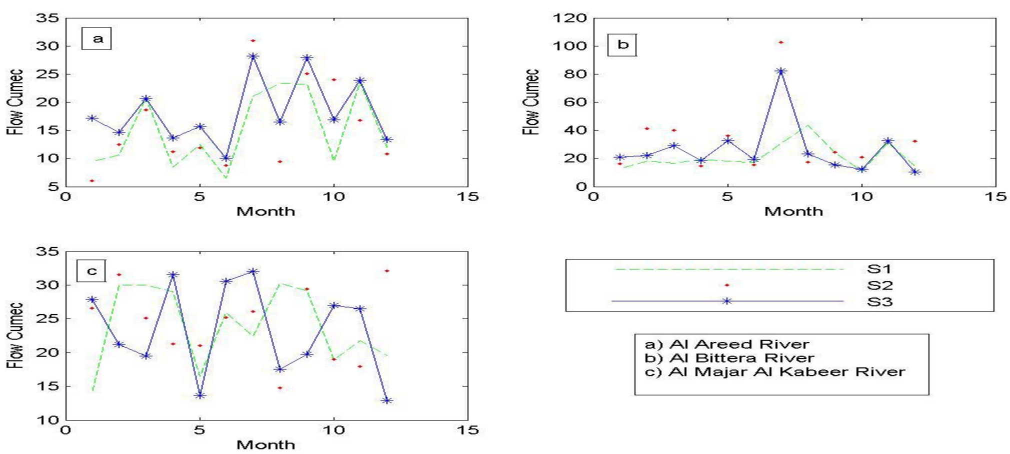


Fig.(16) Optimum Flow for the Three Rivers for all Scenarios for Wet Year Flow.

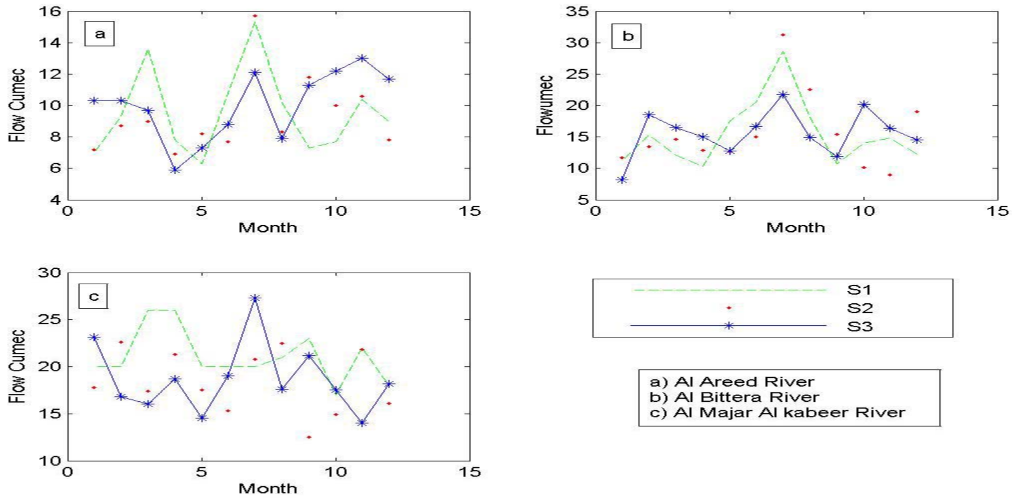


Fig.(17) Optimum Flow for the Three Rivers for all Scenarios for Normal Year Flow.

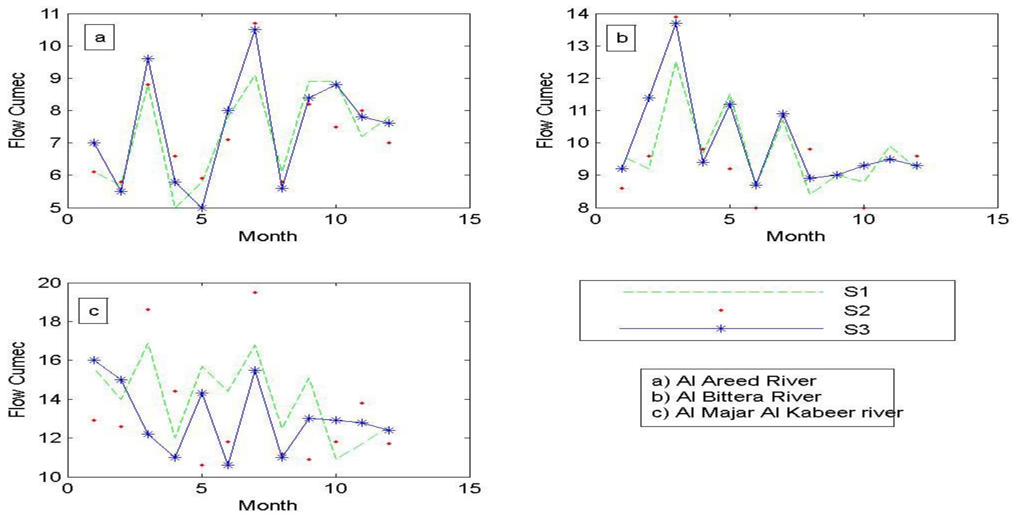


Fig.(18) Optimum Flow for the Three Rivers for all Scenarios for Dry Year Flow.