Optimization of multiple reservoirs releases using Genetic Algorithm: Case study of Ilisu-Cizre reservoirs system

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Abstract

The main purpose of this research is to apply a Genetic Algorithm (GA) to the multi-reservoirs release in which various water utilizations are considered. The GA technique, which is an optimization approach based on the mechanics of natural selection, derived from the theory of natural evolution, was carried out through application to the Ilisu-Cizre reservoirs system on Tigris River. The objective functions are: (1) minimize sum of squared deficit for irrigation annually for Cizre project and (2) maximize annual energy production from Ilisu and Cizre hydroelectric power plants. The results show that the average flow at the Iraqi boarders is (79-88)% from the average flow when the irrigation release lies in the range (79-82)% from the maximum and the energy production is (52.5-60) from the maximum production.

الخلاصة

يهدف هذا البحث الى تطبيق الخوارزمية الجينية لتحقيق امثلية تحديد الاطلاقات المائية من الخزانات المتعددة. طبقت الطريقة على خزاني اليسو–جزرة المقترحة على نهر دجلة ضمن الحدود التركية . تعتمد الطريقة على ميكانيكية الاختيار الطبيعي المشتق من نظرية التطور الطبيعي. دالتي الهدف لهذا البحث هما : (1) تقليل مجموع مربع النقص في الاحتياجات الاروائية السنوية للمشروع الاروائي الذي يتغذى من سد جزرة، (2) تعظيم الانتاج السنوي للطاقة الكهربائية المنتجة من المحطة الكهرومائية من كل من سد اليسو وسد جزرة. اظهرت النتائج بأن ما يصل الى الحدود العراقية من مياه نهر دجلة يتراوح بين (79–88)% من معدل الجريان المفترض بتحقيق نسبة (79–82)% من اعلى احتياج اروائي لمشروع جزرة ونسبة (52.5–60)% من الانتاج الاقصى للطاقة الكهربائية لمحطتي توليد اليسو وجزرة.

Introduction

Water directly controls the diversity of all living beings on the earth. Reservoir operation is a complex problem that involves many decision variables, multiple objectives, as well as considerable risk and uncertainty, (**Oliveira and Loucks, 1997**).

In recent years, there has been an increasing interest in biologically motivated adaptive systems for solving optimization problems. The Genetic Algorithms (GAs) are of the most promising techniques in the natural adaptive system field of Evolutionary Algorithms (EA) and are receiving wide attention, because of their flexibility and effectiveness for optimizing complex systems. Genetic Algorithms use a population of solutions in each iteration instead of a single solution and so they are called population-based approaches, (**Goldberg, 1989**).

Oliveira and Loucks (1997) used GAs to identify the reservoir-operating rules of the example reservoir systems for water supply and hydropower. Genetic algorithm is applied by **Orero and Irving (1998**) to the problem of determining the optimal hourly schedule of power generation in a hydro thermal power system. A multi-reservoir cascaded hydro-electric system with a non-linear relationship between water discharge rate, net head, and power generation is considered.

Sharif and Wardlaw (2000) applied a GA to optimize a real multireservoir system. The objective functions were formulated for two cases: (1) maximizing the hydropower production while allowing deficits to occur in irrigation supplies and (2) minimizing the deficits in irrigation supplies while maximizing the hydropower production. **Raju and Kumar (2004**) used GA to evolve efficient cropping pattern for maximizing benefits for an irrigation project in India. The constraints included continuity equation, land and water requirements, crop diversification, and restrictions on storage. A penalty function approach is used to convert the constrained problem into an unconstrained one. For fixing GA parameters the model is run for various values of population, generations, crossover, and mutation probabilities.

Namchaiswadwong et al. (2006) applied a GA to the practical multiple reservoir release problem in which various water utilizations are considered to the Mae Klong River Basin in Thailand.

Research objectives

The main purpose of this research is to apply a GA model to Ilisu-Cizre reservoirs system to delineate the effect of satisfying the Turkish water demands on the flow of the Tigris River at the Turkish-Iraqi borders.

Recognizing that the operation strategy therein for the time being is under the full control of the Turkish authorities, the model will be run for selected hypothetical operation cases.

Genetic algorithms

Genetic algorithms are search algorithms based on the principles of Darwinian mechanics of natural selection and survival of the fittest (**Goldberg, 1989**).

GAs create a set of artificial chromosomes representing the value of variables, and reproduce a new generation by using bits and pieces of the fittest of the old and introducing new bits and pieces for better measure. They do this process time after time to find the string, which represents the optimal solution. (**Goldberg, 1989**).

A GA generally represents a solution using strings (or chromosomes) of variables that represent the problem. Each string comprises a number of blocks, which represent the individual decision variables of the problem (genes). The number of genes comprised the string depends on the decision variables of the objective function of the problem. The fitness of a chromosome as a candidate solution to a problem is an expression of the value of the objective function represented by it.

The two distinct elements in the GA are individuals and populations. For the initialization of the population, the GA uses randomly chosen object feature vectors from the data set. After initialization, the individuals are evaluated according to the fitness function. For elitism, the population is ranked to determine the best individuals which are left unchanged by selection, mutation, and crossover during the next iteration.

The population is iteratively refined by selection of individuals, application of crossover and mutation operators, re-evaluation of the new population according to the fitness function, and updating the elite solutions.

The Ilisu-Cizre reservoirs system

Tigris at Ilisu

The Ilisu damsite has a catchment area of 35517 km2 and, based on the available data, the annual average inflow is 15842 Mm3. The largest contribution is from the Botan River (156 cumecs average flow at Biloris station),(Ilisu Consortium, 2005), as a result of heavy precipitation in the mountainous region in the Northern and Eastern parts of the catchment area. The Ilisu Project is located in Southeastern Anatolia, between 37° 30’ and 38° 00’ latitude North and 40° 44’ and 42° 02’ longitude East. The rock fill dam and powerplant are located on the Tigris River, 45 km upstream the city of Cizre, (**Ilisu Dam and HEEP, 2005**). The salient features of the dam are shown in Table (1).

Tigris at Cizre

The damsite is located 40 km downstream of the Ilisu damsite and 20 km upstream from the Turkey-Syria borders.

The annual flow mean of the Tigris at Cizre is 16600 MCM for a drainage area of 38295 km^2. More than half of the flows occur during the wet season, essentially between March and May. The driest month is generally September (**Ilisu Consortium, 2005**).

The Cizre project to be implemented in the frame of the GAP development is multipurpose undertaking for both hydropower production (240 MW) and the irrigation of 121000 ha (Table 2). In addition to these goals, Cizre will have the advantage to create a reservoir maintaining more or less constant water levels in the reach between Ilisu and Cizre.

Model formulation

The two reservoirs of the Tigris River system (Figure 1) are considered as a network system and the optimal monthly releases from the reservoirs are to be determined. The twin objectives of this system are minimization of irrigation deficits and maximization of energy generation. These two are conflicting objectives, since one tries to minimize the irrigation deficits, requiring more water to be released to satisfy irrigation demands and the other tries to maximize energy production, which requires higher level of storage to be maintained in the reservoir to produce more energy

The Objective Functions

The objective functions considered are as follows:

Minimize sum of squared deficit for irrigation annually for Cizre project (F_1):

$$Min.SQDV = \sum_{t=1}^{T} \left(ID_{2,t} - IR_{2,t}\right)^2 \qquad t=1,2,3,\ldots,T \qquad (1)$$

where

SQDV : Sum of squared deviation of release from demand (MCM)2 ;

ID2,t : Irrigation demand of Cizre Project in month t (MCM) .

IR2,t : Release for irrigation from Cizre during month t (MCM).

Maximize annual energy production (F_2):

$$Max.En = \sum_{t=1}^{T} \left(En_{1,t} + En_{2,t}\right) \qquad t=1,2,3,\ldots,T \qquad (2)$$

where

En : Energy production (GWh).

En1,t : Energy production from Ilisu HPP in month t (GWh).

En2,t : Energy production from Cizre HPP in month t (GWh).

The Constraints

The model is subjected to the following constraints:

Irrigation release:

The releases during a particular month from the system should be sufficient to meet the crop-water requirements,

$$ID_{2,t}\ \min \le IR_{2,t} \le ID_{2,t}\ \max \qquad t=1,2,3,\ldots,T \qquad (3)$$

where

$ID_{2,t}max$,$ID_{2,t}min$: Maximum and minimum irrigation demands for Cizre projects, (MCM), respectively.

$IR_{2,t}$: Release for irrigation from Cizre during month t (MCM) .

Reservoir capacity:

The water content in the reservoir should not be less than the minimum storage limit and not exceed the storage capacity at any time.

$$S_1 \min \leq S_{1,t} \leq S_1 \max \qquad t=1,2,3,\ldots,T \qquad (4)$$

$$S_2 \min \leq S_{2,t} \leq S_2 \max \qquad t=1,2,3,\ldots,T \qquad (5)$$

where

S1max, S1min : Maximum and minimum storages for Ilisu reservoir, (MCM), respectively.

S2max ,S2min , S 2,t : Same as above but for Cizre reservoir.

Energy production limits:

$$En_1 \min \leq En_{1,t} \leq En_1 \max \qquad t=1,2,3,\ldots,T \qquad (6)$$

$$En_2 \min \leq En_{2,t} \leq En_2 \max \qquad t=1,2,3,\ldots,T \qquad (7)$$

$$H_{1,t} \min \leq H_{1,t} \leq H_{1,t}\max \qquad t=1,2,3,\ldots,T \qquad (8)$$

$$H_{2,t} \min \leq H_{2,t} \leq H_{2,t}\max \qquad t=1,2,3,\ldots,T \qquad (9)$$

where

En1,t : Energy production from Ilisu HPP in month t (GWh).

En1max : Maximum energy production from Ilisu HPP (GWh).

En1min : Compulsory minimum energy production from Ilisu HPP (GWh).

H1,t : Ilisu HPP operating head during month t (m).

H1,tmax, H1,tmin : Maximum and minimum Ilisu HPP operating heads (m) .

En2,t , En2max, En2min ,H2,t , H2,tmax, H2,tmin : Same as above but for Cizre HPP .

Continuity (mass balance) constraints:

The mass balance between the inflows and outflows of each reservoir system makes the continuity constraint. The overflow from the Ilisu reservoir will act as the inflow for the Cizre reservoir. The continuity equations for the respective reservoirs are stated as follows:

S1,t = S1,t-1 +In1,t + P1,t - Ev1,t - R1,t t=1,2,3,…,T (10)

S2,t = S2,t-1 + In2,t + P2,t - Ev2,t- IR 2,t- R2,t – (RT2,t+RS2,t) t=1,2,3,…,T (11)

R1,t = RHp1,t +C*RO1,t

R2,t = RHp2,t +C*RO2,t

In2,t = R1,t +TInt (12)

where

S1,t : Ilisu reservoir storage at the end of month t (MCM) .

S1,t-1 : Ilisu reservoir storage at the beginning of month t (MCM).

In1,t : Inflow to Ilisu reservoir during month t (MCM).

P1,t : Precipitation over Ilisu reservoir during month t (MCM).

Ev1,t : Evaporation losses from Ilisu reservoir during month t (MCM)

R1,t : Total release from Ilisu dam during month t (MCM).

RHp1,t : Release from Ilisu HPP to the main Tigris River D/S during month t (MCM).

RO1,t : Overflow from Ilisu spillway and other exits to the main Tigris River D/S during month t (MCM)

IR 2,t: Release for irrigation from Cizre during month t (MCM)

TInt : Inflow from tributaries between Ilisu and Cizre during month t (MCM).

S2,t, S2,t-1, In2,t, P2,t, Ev2,t, R2,t , RHp2,t , RO2,t: Same as above but for Cizre reservoir.

C : Factor (C=1 if RO1,t or RO2,t > 0 and C=0 otherwise)

RT2,t : Turkish requirements other than irrigation D/S Cizre during month t (MCM).

RS2,t : Syrian requirements during month t (MCM|).

The initial storage of the reservoirs is assumed at 50% of their capacity.

Release constraints

RHp1,tmin ≤ RHp1,t ≤ RHp1,tmax (13)

RHp2,tmin ≤ RHp2,t ≤ RHp2,tmax (14)

Iraqi requirements:

It is assumed that 15% of the irrigation releases from Cizre reservoir returns to the downstream reach of Tigris River as the return flow (Illisu Consortium, 2005). The Iraqi minimum requirements at the borders have been estimated as (200 cumecs), that is:

$$IQR_t \geq 518 \qquad t=1,2,3,\ldots,T \qquad (15)$$

where

IQR t : Iraqi requirements from Tigris River at the boarders in month t (MCM).

To bring both objectives into the same units, the irrigation and energy objectives are non-dimensionalized. So the final fitness function for the model is as follows:

$$F = a\sum_{t=1}^{T}\left[\left(1-\frac{D_{2,t}-IR_{2,t}}{D_{2,t}}\right)^2\right] + b\sum_{t=1}^{T}\left[\left(1-\frac{En_1\max - En_{1,t}}{En_1\max}\right)^2 + \left(1-\frac{En_2\max - En_{2,t}}{En_2\max}\right)^2\right] \qquad (16)$$

where

a, b : Constant weights to be chosen based on scheduled priority.

The final fitness is to minimize F dually satisfying the constraints in Equations (3) to (15).

Sensitivity Analysis

Sensitivity analysis for GA parameters is carried out for determining the number of generations, size of population, probability of crossover, and probability of mutation. Fixing the population size as 600, probability of crossover as 0.7, and that of mutation as 0.04, the number of generations is varied from 10 to 1000; an optimum value was found at 400. Taking the number of generations as 400, the population size is varied from 10 to 600; an optimum value is found to be 100. The probability of crossover (pc) is varied from 0.10 to 0.90 and the best value was 0.80. For mutation, it is varied from 0.001 to 0.09. It has been observed that the most likely results were at mutation (pm) of 0.04.

Model Application and Results

The GA is applied for a sufficiently long period, 50 years, in which T=600 month, which can well represent the stationarity in the time series. Three operation cases were chosen for the model. These are:

II-1: Max S1,t =100% S1,t and Max S2,t = 100% S2,t t=1,2,3,… ,600

II-2: Max S1,t = 85% S1,t and Max S2,t = 75% S2,t t=1,2,3,… ,600

II- 3: Max S1,t = 75% S1,t and Max S2,t = 60% S2,t t=1,2,3,… ,600

It is mentioned in **Ministry of Irrigation (2002**) that a 50% of supply from the total irrigation demand would result in a 77% of the total expected crop production. Consequently, this 50% have been considered as one of the limits for the irrigation supply; the other limit was considered to be the 100%.

A set of non-dominated Pareto optimal solutions are obtained as the output of the multi-objective GA. The pattern of the Pareto optimal solutions for the three cases are shown in Figure (2). The Pareto front generated depicts that two objective functions, minimization of total irrigation deficits and maximization of energy production, is well distributed along the Pareto front. The results for this model for the three considered cases and for the considered operation horizon {that is (600) months, starting with October of year 1 to September of year 50} are shown in Figures (3) to (14).

Figures (3) to (5) present the monthly release for the Cizre irrigation projects. For the case (II.1), the demand is fulfilled between 60% to 100%. For the other cases this range was between (58%-100%) and (56%-100%), respectively.

Figures (6) to (8) show the monthly energy generated from Ilisu HPP for the three considered cases. These figures indicate that the energy values are within the minimum and maximum monthly ranges which were in the range between (34%-81%) , (34%-82%), and, (33%-83%) from the maximum amount for the cases (II.1), (II.2), and (II.3), respectively.

For Cizre HPP, the monthly energy generation represented (23%-82%) of the maximum value for the case II.1, (30%-82%) for the case II.2, and (32%-81%) for the case II.3. Figures (9) to (11) show the monthly energy generated from the Cizre HPP.

For the Iraqi share from Tigris River that reaches the Iraq-Turkey borders, the application of this model indicates that the expected amount would not fulfill the minimum monthly requirements for 43.33% of the time horizon in case II.1 and 43.83% in case II.2 and 43.50 in case II.3. Figures (12), (13), and (14) clearly show these results.

However, as mentioned previously, the estimated minimum Iraqi demand of (200 cumecs) {that is, 518 MCM/month} is just the minimum and only for survival of Iraqi water use in the Tigris basin; it represents less than (9.80%) of the expected irrigation need {or (3.57%) of the expected irrigation needs in 2020}.

Analysis of the Results

Satisfying the irrigation demands:

The irrigation demand for Cizre projects have been satisfied in the range (50%-100%) during the considered operation horizon, starting with October of year 1 and ending with September of year 50. This satisfaction could be summarized as follows:

Range %	**No. of months**			**% From the considered operation time**		
Case	II-1	II-2	II-3	II-1	II-2	II-3
90-100	93	88	98	15.50	14.67	16.33
80-89	202	186	177	33.67	31.00	29.50
70-79	252	284	257	42.00	47.33	42.83
60-69	53	41	62	8.83	6.84	10.34
50-59	-	1	6	-	0.16	1.00
Total	600	600	600	100	100	100

Considering a reference range of 70% of the demand, it is noticed that no shortage have been seen in 91.17% of the total months by case (II.1), 93% by case (II.2), and 88.66% by case (II.3).

The energy generation from Ilisu HPP:

The energy generated from the Ilisu HPP by mode lI-I varied from one case to another, but in all cases this value was between the maximum and the minimum limits. The ranges from the maximum energy and number of months each range has been fulfilled are summarized as follows:

From (50%-80%) of the maximum energy was generated in 80.66% of the considered operation time by case II.1, 80.5% in case II.2, and 81.00% in case II.3.

Range %	No. of months			% From the considered operation time		
Case	II-1	II-2	II-3	II-1	II-2	II-3
80-89	3	1	8	0.50	0.17	1.33
70-79	74	58	79	12.33	9.67	13.17
60-69	183	185	172	30.50	30.83	28.67
50-59	224	239	227	37.33	39.83	37.83
40-49	97	108	99	16.17	18.00	16.50
30-39	19	9	15	3.17	1.50	2.50
Total	600	600	600	100	100	100

The energy generation from Cizre HPP:

The energy generated from the Cizre HPP by model-I is between the maximum and the minimum limits. The percentage range from the maximum limit for each case with the corresponding time percentage are tabulated below:

Range %	No. of months			% From the considered operation time		
Case	II-1	II-2	II-3	II-1	II-2	II-3
80-89	2	2	2	0.33	0.33	0.33
70-79	46	35	41	7.67	5.83	6.83
60-69	141	157	175	23.50	26.17	29.17
50-59	227	256	211	37.83	42.67	35.17
40-49	152	128	138	25.33	21.33	23.00
30-39	32	22	33	5.34	3.67	5.50
20-29	1	-	-	0.17	-	-
Total	600	600	600	100	100	100

From these results it can be concluded that (50%-90%) of the maximum energy is satisfied by 69.33% of the time horizon according to case II.1, 75.00% in case II.2, and 71.50% in case II.3.

The Iraqi water demand at the borders:

In the three cases of Model II, the minimum amount of water requirements at the Iraqi-Turkish borders has not been fulfilled in the months June, July, August, September, October, November, and December. During the other five months, that amount that corresponds to the minimum Iraqi requirements is in the range of >100% from the minimum limit; the maximum ranges being in the months April, and May. The range of the shortage is shown below.

Month	Case	% From the Iraqi minimum requirements										No. of months	Total no. of months
		0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99		
June	II.1	-	-	-	-	-	-	-	-	4	6	10	50
	II.2	-	-	-	-	-	-	-	-	4	8	12	50
	II.3	-	-	-	-	-	-	-	-	4	7	11	50
July	II.1	4	15	8	4	-	3	7	-	5	2	48	50
	II.2	9	10	8	4	-	2	7	1	5	2	48	50
	II.3	8	11	8	4	-	2	8	1	4	2	48	50
August	II.1	35	8	5	1	1	-	-	-	-	-	50	50
	II.2	33	9	6	1	1	-	-	-	-	-	50	50
	II.3	36	9	2	2	1	-	-	-	-	-	50	50
September	II.1	39	9	2	-	-	-	-	-	-	-	50	50
	II.2	45	3	2	-	-	-	-	-	-	-	50	50
	II.3	46	2	2	-	-	-	-	-	-	-	50	50
October	II.1	39	5	3	-	2	-	-	-	1	-	50	50
	II.2	40	4	3	-	2	-	-	-	1	-	50	50
	II.3	39	5	2	1	1	1	-	-	1	-	50	50
November	II.1	15	5	2	-	1	8	2	3	1	-	37	50
	II.2	31	5	1	1	2	6	2	3	1	-	37	50
	II.3	13	7	2	-	2	5	4	3	-	-	37	50
December	II.1	-	-	-	-	-	1	3	3	7	1	15	50
	II.2	-	-	1	-	-	1	4	1	7	2	16	50
	II.3	-	-	1	-	-	2	1	3	6	2	15	50

Conclusion

The Genetic Algorithm has been used to solve the formulated multi-objective functions optimization model for Ilisu-Cizre reservoirs system with three operation cases, (1: Max $S_{1,t}$ =100% $S_{1,t}$ and Max $S_{2,t}$ = 100% $S_{2,t}$), (2: Max $S_{1,t}$ = 85% $S_{1,t}$ and Max $S_{2,t}$ = 75% $S_{2,t}$), and (3:Max $S_{1,t}$ = 75% $S_{1,t}$ and Max $S_{2,t}$ = 60% $S_{2,t}$). The major findings of this research are summarized as follows:

1-With respect to the energy generated from the Ilisu HPP, according to the model, (50%-80%) of the maximum energy was generated in more than 80% of the considered operation time by the three cases.

2-With respect to the energy generated from the Cizre HPP, In this model, (50%-90%) from the maximum energy is satisfied by (69.33, 75.00, 71.50)% of the time horizon according to cases 1, 2, and 3 respectively.

3-With respect to the Iraqi requirements at the borders, the minimum amount of water requirements at the Iraqi-Turkish borders considered as 518 MCM/month. In the three cases of model II, this amount has not been fulfilled in the months June, July, August, September, October, November, and December.

Table (1): Salient features of Ilisu reservoir, (Ilisu Dam and HPP, 2005)

Characteristic	Units	Quantity
Minimum operation level (MOL)	m.a.s.l	485.00
Normal water level (NWL),	m.a.s.l	525.00
Maximum water level (MWL)	m.a.s.l	526.80
Dam crest level	m.a.s.l	530.00
Dead storage capacity (Inactive) at MOL	Mm^3	2950
Gross storage capacity at NWL	Mm^3	10410
Live storage capacity (Active) at NWL	Mm^3	7460
Reservoir surface area at MOL	Km^2	100
Reservoir surface area at NWL	Km^2	300
Reservoir surface area at MWL	Km^2	313
Catchments area	Km^2	35517
Spillway max. discharge at MWL	cumecs	18000
Average annual inflow at damsite	Mm^3	15450
Average yearly discharge at damsite	cumecs	490
No. of turbines	units	6
Max. discharge through turbines	cumecs	1200
Installed capacity	MW	6×200
Annual energy	GWh	3833
Specific energy	KWh/m^3	0.313
Power intake level	m.a.s.l	460.00
Tailwater level	m.a.s.l	404.40

Table (2): Salient features of Cizre reservoir, (Ilisu Dam and HPP, 2005)

Characteristic	Units	Quantity
Minimum operation level (MOL)	m.a.s.l	392.00
Normal water level (NWL)	m.a.s.l	404.40
Dead storage capacity (Inactive) at M.O.L.	Mm^3	152
Live storage capacity (Active)	Mm^3	208
Gross storage capacity at NWL	Mm^3	360
Reservoir surface area at normal water level	Km^2	21
Spillway discharge	cumecs	18700
Average Annual inflow	Mm^3	16600
Average yearly Discharge of Tigris river at damsite	cumecs	526
Catchments area	Km^2	28295
Irrigated area	ha	121000
No. of turbines	unit	3
Max. discharge through turbine	cumecs	743
Installed capacity	MW	3×80
Annual energy	GWh	1208
Specific energy	KWh/m^3	0.095
Tailwater level	m.a.s.l	368.8

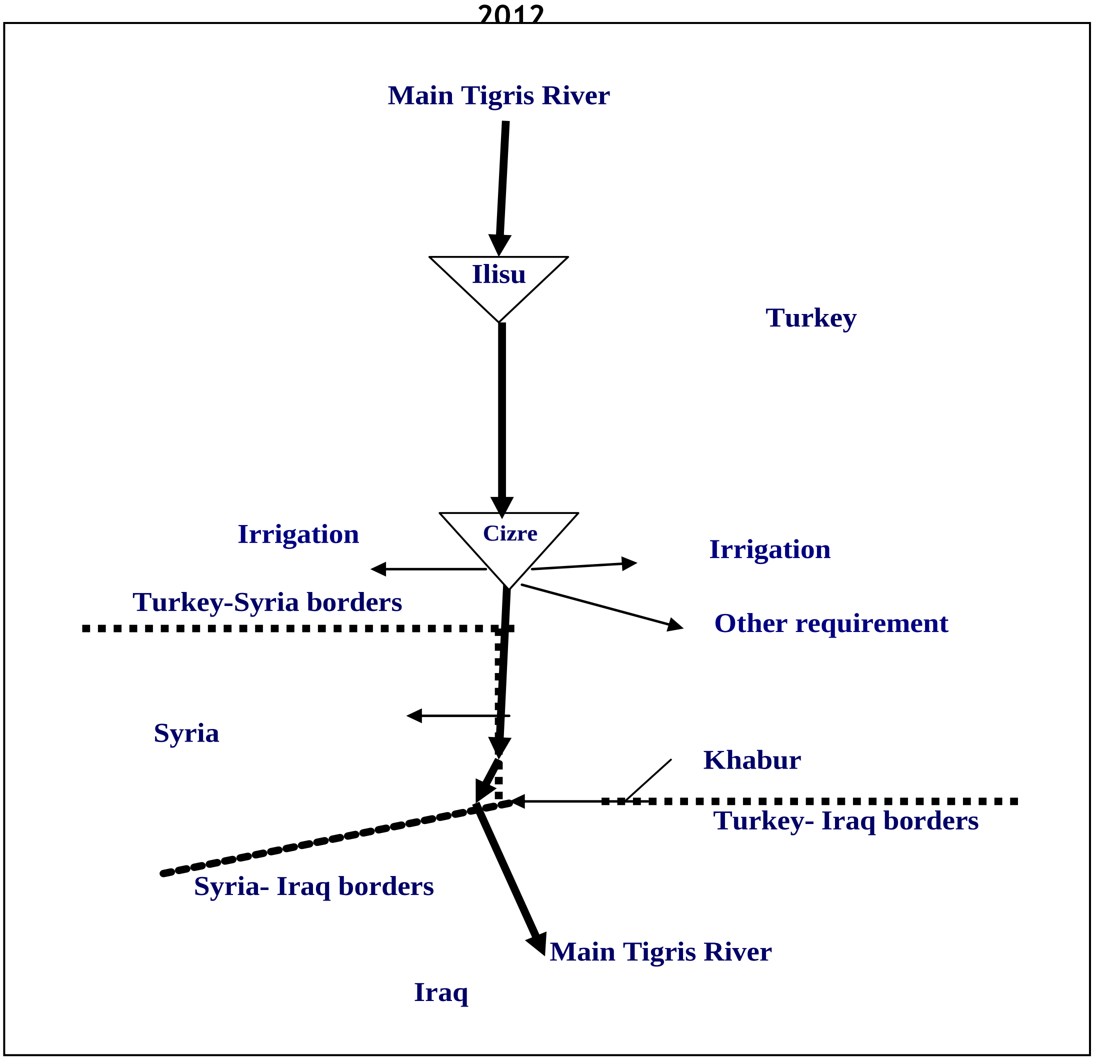

Figure (1): Schematic diagram of Ilisu-Cizre reservoirs system

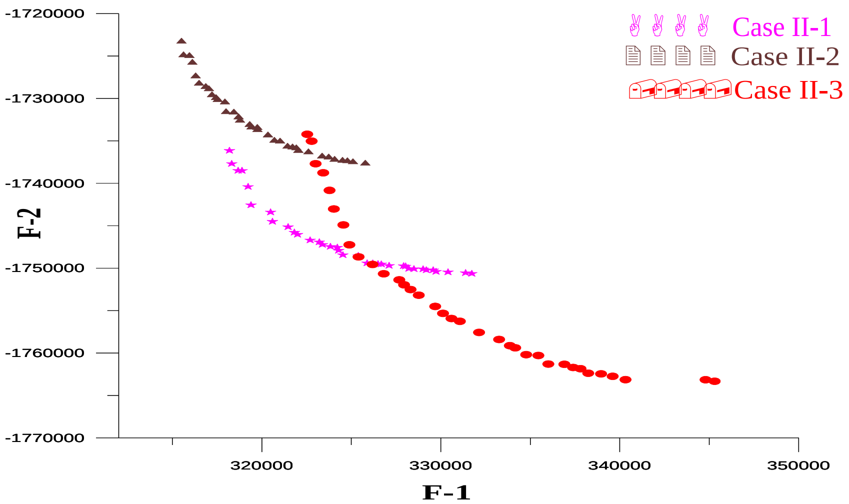

Figure (2): Pareto front showing the two objective functions for three cases of the model

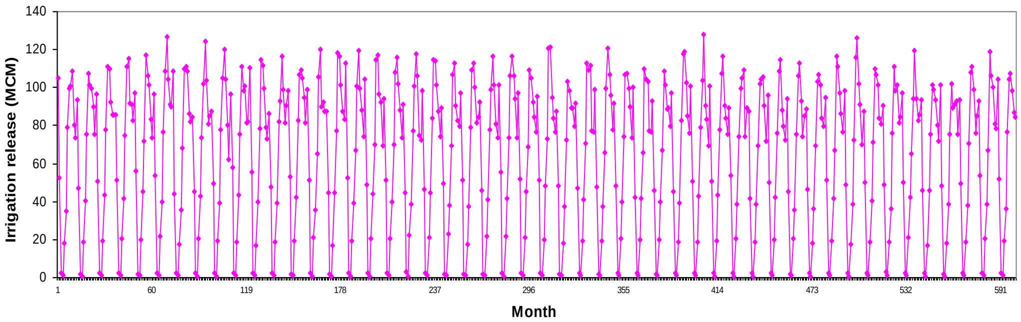

Figure (3): Monthly irrigation release for Cizre irrigation projects according to the operation case II.1

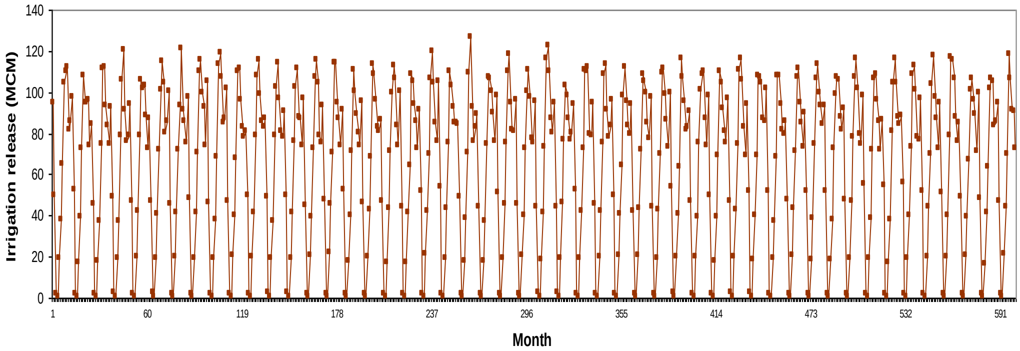

Figure (4): Monthly irrigation release for Cizre irrigation projects according to the operation case II.2

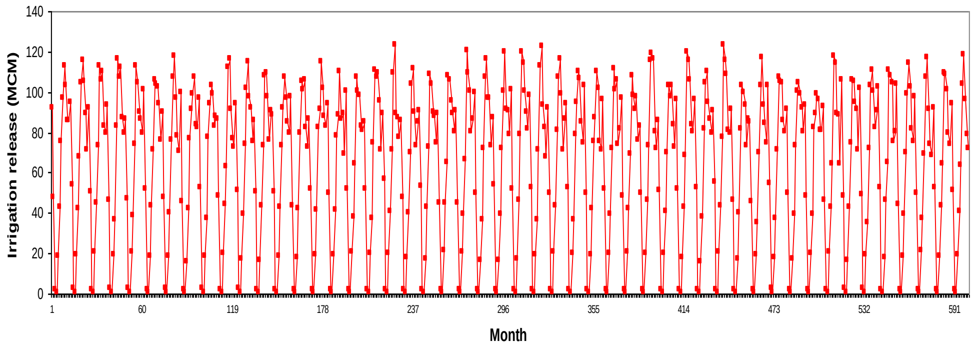

Figure (5): Monthly irrigation release for Cizre irrigation projects according to the operation case II.3

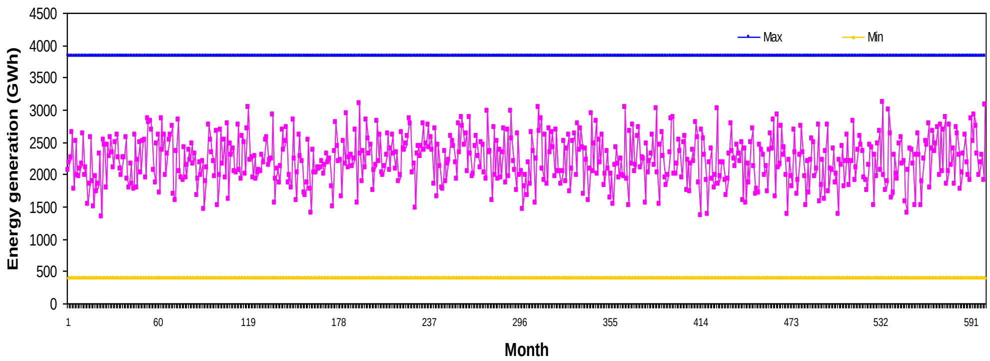

Figure (6): Monthly energy generation from Ilisu HPP according to the operation case II.1

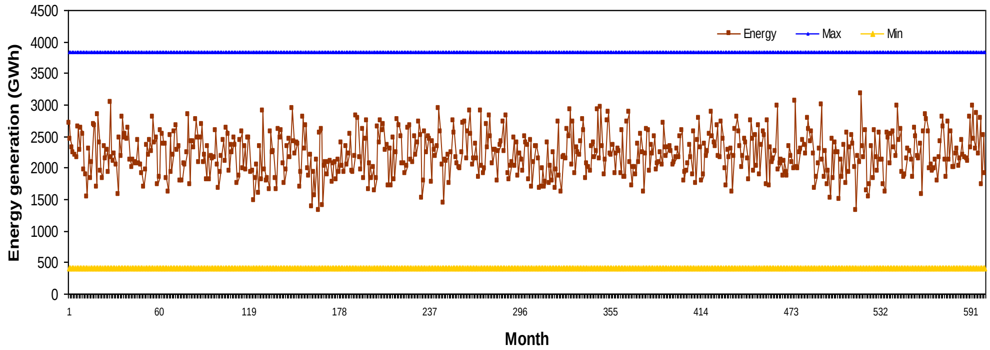

Figure (7): Monthly energy generation from Ilisu HPP according to the operation case II.2

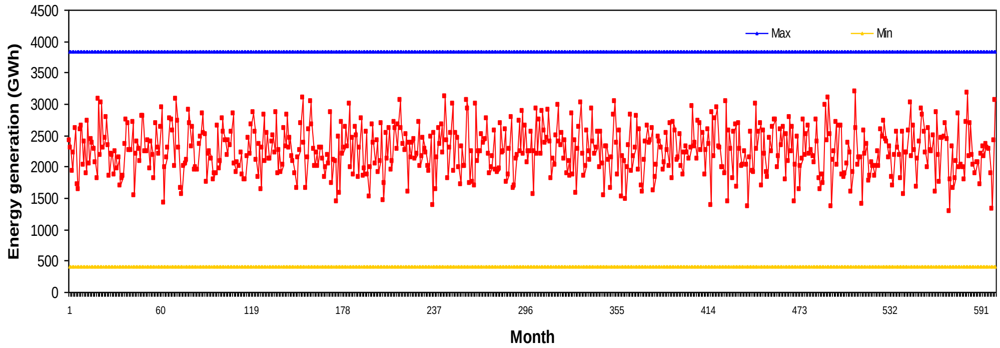

Figure (8): Monthly energy generation from Ilisu HPP according to the operation case II.3

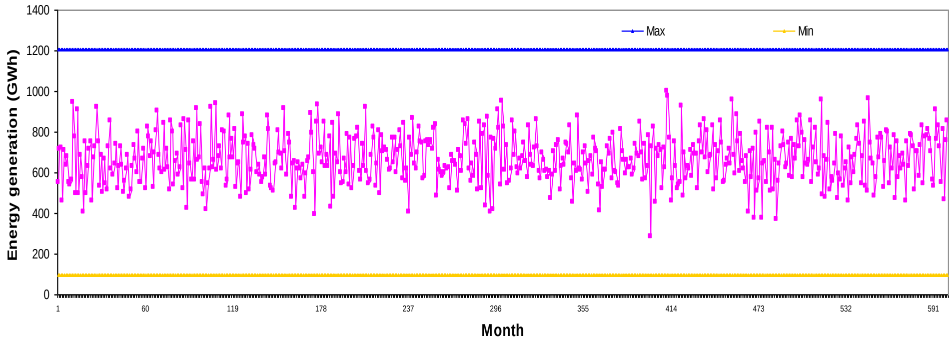

Figure (9): Monthly energy generation from Cizre HPP according to the operation case II.1

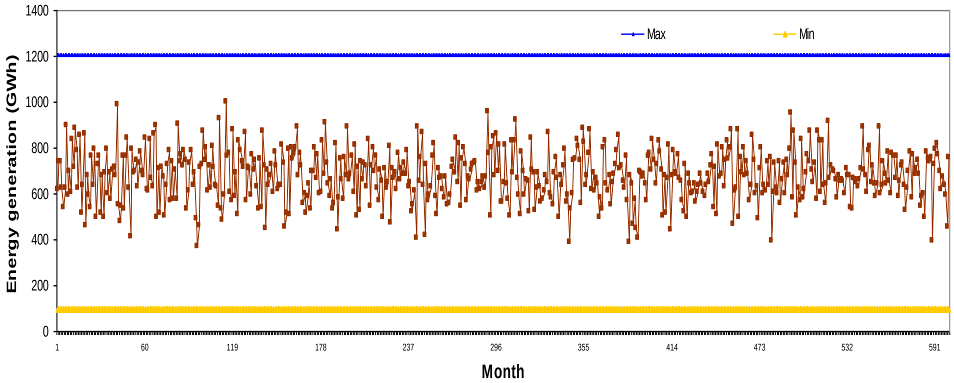

Figure (10): Monthly energy generation from Cizre HPP according to the operation case II.2

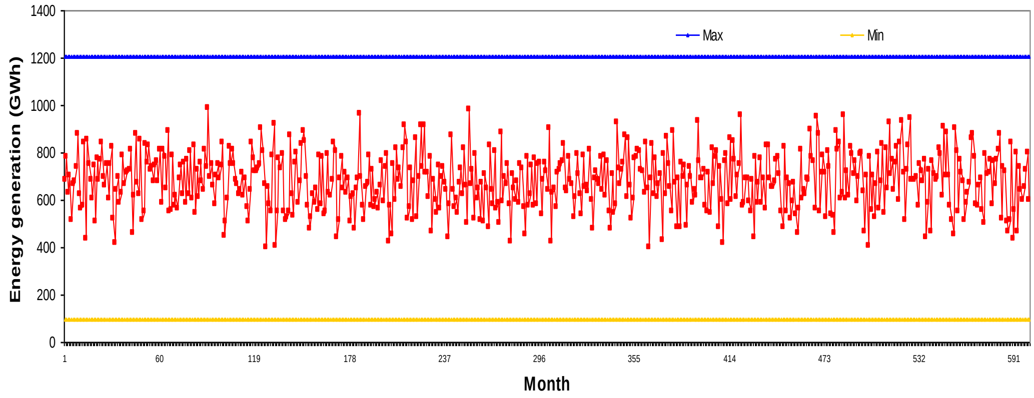

Figure (11): Monthly energy generation from Cizre HPP according to the operation case II.3

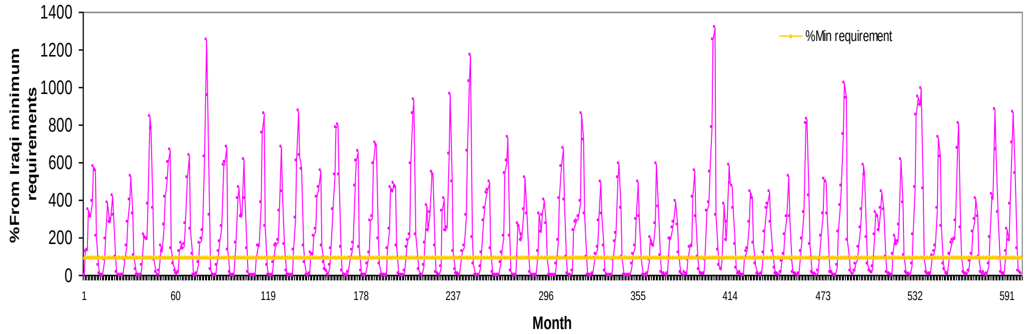

Figure (12): Iraqi share from Tigris River at the borders according to the operation case II.1

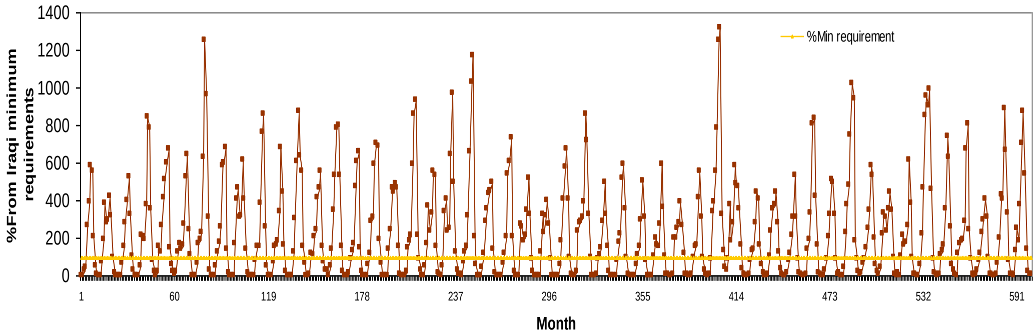

Figure (13): Iraqi share from Tigris River at the borders according to the operation case II.2

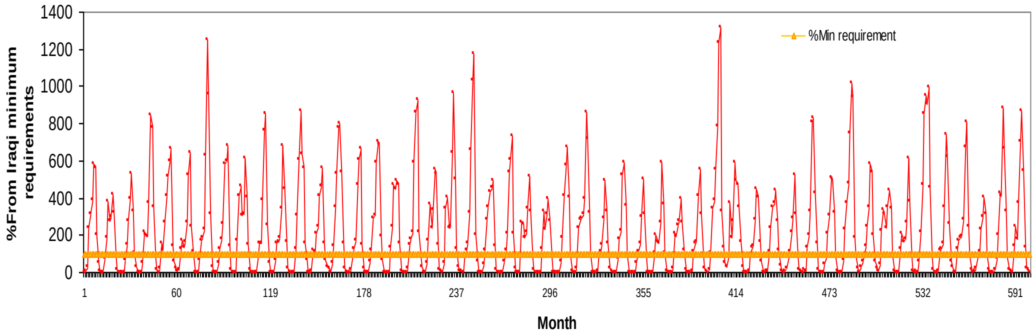

Figure (14): Iraqi share from Tigris River at the borders according to the operation case II.3

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