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Planning and Decision Making Under Uncertainty (Mosul Reservoir Optimal Operating Policy- Case Study)

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ABSTRACT

This study is concerning the planning and decision making process of water resources projects under uncertainty. It includes a mathematical analysis to optimize the operation of the Mosul reservoir sought to achieve two conflicting goals, diverting water from for irrigation and releasing water for hydroelectric generation. Four methods of solutions have been implemented. These are: weights, constraints, goal attainment, and step method. The results reveal that the used methods gave the optimal solution by allocating 5906 million cubic meters/ year for irrigation and 1600 Gw-hour/year for power generation),(6236, 1555), (6188, 1558),and (6121,1568) under the given inflow conditions . The current study suggested that the average value of these solutions i.e (6113, 1570) can be taken as a compromise solution to the problem. It is believed that this solution has a good chance to be selected by the decision-maker, because it contains the least possible degree of subjectivity.

Keywords:

Decision Making; Multi-Objective Analysis; Reservoir operation; Uncertainty.

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1. INTRODUCTION

Uncertainty in future state of the availability of water may increase the gap between supply and demand. This is one of the main reason motivates people to construct storage projects. However, a reservoir system may have conflicting goals and requirements and reservoir operating policies must reflect this. Also, factors affecting reservoir operation and management perspectives may change over time and operational procedures, therefore, should be so designed such that they are responsive to such changing needs and conditions [1]. The solution to the problem is difficult because of the large number of variables involved, the non-linearity of system dynamics, the stochastic nature of future inflows, and other uncertainties inherent in this sorts of systems. The uncertainty associated with reservoir operations is further increased due to the ongoing hydrological impacts of climate change[2].

The determination of optimum reservoir operating rules for systems of multiple conflicting objectives is still a difficult task despite many publications in this field. The operation of a single reservoir for a single function does not present any analytical problems, but the same is not true when a reservoir fulfills a number of potentially conflicting objectives. For a typical reservoir, the task of problem formulation, that is appropriately representative of actual system dynamics, is accomplished by specifying mass balance relationships within the reservoir network. Additionally, for a measure of realism in system operation, a set of constraint equations and other rating equations are also usually specified. Al-Mohseen, (2003) [3] had analyzed the operation of Kabini reservoir in India using goal attainment for multi-objective analysis. He concluded that the mathematical relationships describing the interaction among various components of a reservoir system are, in general, complex. (Kuo, Cheng and Chen, (2003)[4] adopted multipurpose operation by most reservoirs in Taiwan in order to maximize the benefits of power generation, water supply, irrigation and recreational purposes. A multi-objective approach was used by the weighting method, in which different weighting factors are used for different purposes, Genetic algorithms with characteristics of artificial intelligence were applied to obtain the optimal rule curves of the multi-reservoir system under multipurpose operation in ChouShui River Basin in central Taiwan. The model results reveal that different shapes of rule curves under different weighting factors on targets can be efficiently obtained by genetic algorithms. Pareto optimal solutions for a trade-off between water supply and hydropower were obtained and analyzed. Consoli, Matarazzo and Pappalardo, (2008)[5] introduced a multi-objective optimization technique for the operation of an irrigation reservoir. The study deals with two different objective functions: the minimization of reservoir release deficit from the irrigation demand and the maximization of net benefit by the demand sector. Multi-objective optimization was performed through the Constraint method for Non-dominated set of release strategies is generated. The interactive analytical Step method was applied to find the best compromise solution. The proposed water allocation model was applied to the Pozzillo reservoir operation that supplies the Catania Plain irrigation area (Eastern Sicily). Heydari, Othman and Taghieh, (2016)[6] introduced performance optimization of the system of Karun and Dez reservoir dams and investigated with the purposes of hydroelectric energy generation and providing water demand in 6 dams. Multi-objective optimization was used by weighting method and Constraint method. The results show that the role of objective function structure for generating hydroelectric energy in weighting method algorithm is more important than water supply. Nonetheless by implementing constraint method algorithm, we can both increase hydroelectric power generation and supply around 85% of agricultural and industrial demands. Shiyekar, (2018) [7] developed model to optimize the operation of multipurpose reservoir and derive reservoir operating rules for optimal reservoir operations. The objectives functions used in the model are minimization of irrigation deficits and maximization of hydropower generation. Weighting method was used, weights were a given to objective function depending up on the priority of the objective function. The present model was applied to the Ukai reservoir in Gujarat State, India, can satisfy downstream irrigation demand. Villa *et al.*, (2018)[8] introduced a novel multi-objective optimization modeling framework that uses the constraint method and genetic algorithms as optimization techniques for the operation of multipurpose reservoirs. For reservoir design at the operational stage, the main objective function minimizes the cost of the total annual water shortage for irrigation areas connected to a reservoir, while the secondary one maximizes its energy production. The study was applied to Carlos Manuel de Céspedes reservoir. The results highly demonstrate the applicability of the model, obtaining monthly releases from the reservoir, degree of reservoir inflow regulation, water shortages in irrigation areas, and the energy generated by the hydroelectric plant. Anand et.al., (2018)[9]introduced model that weighting method and Genetic Algorithm employed to two reservoirs in Ganga River basin, India in order to obtain the optimal reservoir operational policies. The objective function has been added to reduce the yearly sum of squared deviation from preferred storage capacity and required release for the irrigation purpose and the other objective function of the overall energy generated. Three conditions of priority (supply priority, power priority, and equal priority) have been devised. It has been concluded that model-derived optimal reservoir operation rules are competitive and promising, and can be efficiently used for the derivation of operation of the reservoir.

In this study, a four of the available methods to be applied for the improvement of operation of Mosul reservoir on Tigris river, Iraq.

2. PLANNING PROSESS

The process of selecting the policy of operating a water resource system normally involves three stages viz. i. Quantification of the objective function, ii. Formulation of the alternatives, and iii. Selection of the proper plan. In the quantification stage a measure of the objective achievement should be set. However, there is no need to quantify all the considered objectives in commensurable units. For example; in the present study, the unit of the allocated water for irrigation does not match that of hydropower generation.

Many water resources planning problems require a multi-objective analysis approach. This would complicate the process for the analysts as well as for the decision maker as they are facing more difficult challenges to identify a certain plan. There is virtually no way in which the selection step can be normative procedures, [10]. No standard method is available to select the more preferable plan. However, the interactive between the analyst and the decision maker is crucial at this stage in sense that the later should rank his preferences in order to reach a feasible plan .Loucks, *et al.*, (1981) [10] stated that decision makers cannot be expected to know what they want until they know what they can get. On the other hand, the analyst should have an idea about the process of decision making. Those two involving parties must be work together to identify, quantify, formulation and selection the prospective plan. Basically, the measure burden is laying on the shoulders of the analysts.

Methods of searching for the best solutions may be difficult for the decision-maker and the difficulty increases when the goals are conflicting. So the analyst must define a set of non-dominant solutions called the Pareto set in order to enable the decision-maker to choose the most preferred solution. There are many methods used to build Pareto surface such as weighting method, constraint method, goal attainment method, the step method, and others[11] -[14].

3. MULT-OBJECTIVE ANALYSIS

Multi-objective analyses do not yield single optimal solutions, rather they are more useful at identifying the trade-offs among conflicting non-commensurable objectives[10]. Multi-objective analyses should assist those responsible for making decisions by illustrating the range of possible decisions and the impacts of the alternative and competing plans.

Multi-objective optimization problems involve more than one objective function and are usually defined in terms of a scalar combination of such objective functions in order to simplify the task of problem formulation. Most real world decision-making problems need to address multiple planning and developmental objectives. Additionally, for purposes of operating policy design, a multiple criteria framework is commonly evident in these problems. It follows that such complex problems can rarely be adequately represented in terms of a single-objective and a single criterion framework, [11].

Multi-objective optimization problems for cabinets represent the optimal optimization of many differentiated targets. The multi-purpose reservoir often has more than single purpose, For example, the case study used here comprises of two main goals, viz. demand for irrigation and hydropower generation. One can observe that these objectives are in conflict and contradictory in nature with each other, also it can be noticed that the increase of benefits resulting from hydropower generation requires an increase in the water level in the reservoir and this requires the reduction of the amount of water that should be diverted for irrigation. The reservoir operators and decision makers should think in a possible trade-offs between the two objectives before choosing the most optimal policy.

This study is to explore the power of the above listed methods in identifying the proper plan and consequently, the pertaining operating policy of the reservoir system under study. The evaluation of the prospective solution addressed in a comparison fashion which would hopefully leads to the satisfaction of the decision maker involves in the selection process.

4. PLAN FORMULATION

In order to achieve the objective of the present study, different optimization models have been applied following the usually used steps. Firstly it was required to identify an ideal point. The ideal point consists of maximizing each individual objective with a standalone optimization model regardless the values of the other objectives are. If the number of objectives is k then the mathematical formulation of model-j is as follows:

Maximize $F_j(x)$ ..……. (1)

s.t:

$g_i(x) \leq 0; i=1,2,...,m$ ……… (2)

j=1, 2,….., k

Where, $F_j(x)$ is the individual objective function, this it subjected to some constraints $g_i(x)$.

The optimal values emerged from all models constitute of the ideal point $[F_j(x^*)]$,though it is inaccessible in sense of multi-objective analyses, but It can be seen in the following analyses that this point is crucial for some approaches used in this study.

Secondly the solution selection among many optimal solutions of multi-objective problems involves., a number of iterative and interactive of many schemes which have been proposed in the literature. Among these are weighting method, constraint method, goal attainment method, and step method.

i. Weighting Method

This method was proposed by [15] and involves assigning a non-negative relative weight toeach objective, the multi objective functions transforms into single objective function is:

Maximize $W_1f_1+ W_2f_2+……+ W_kf_k$…….. (3)

s.t.

In addition to equation (2) above.

The W_j are usually normalized so that$\sum_{j=1}^{k} W_j=1$.

Where, the W_1, ...W_k are weights assigned to the individual objectives, f_1,.....f_k . This method can be used to generate non-dominated Pareto solution set by utilizing various values of W_j.

ii. Constraint Method

This method was first proposed by [16], and includes choosing one of the objectives functions for optimization and other objectives functions are converted into constraints such as:

Maximize $F_p(x)$................ (4)

s.t.

$F_j(x) \geq L_j ;\forall j \neq p$ .... (5)

In addition to equation (2).

where , $F_p(x)$ is the objective function as the primary objective, $F_j(x)$ are the other objective function , L_j are the target levels, Feasible ranges of these levels are determined from the ideal solution. To find Pareto surface, L_j should gradually varied and the problem is solved until a satisfied number of points have been obtained.

iii. Goal-Attainment Method

This method is a powerful tool to find the best-compromise solution and is not subjected to convexity limitations of any kind[17] and [18].This method includes giving a target vector Tj, and the relative degree of under- or over achievement of goals is expressed as a vector of weights Wj. Mathematically:

Minimize D .... (6)

s.t.

$W_j[T_j-F_j(X)] \leq D$; j=1,2,...,k.............. (7)

Plus equation (2)

Where, D is the “distance” of each non-dominated solution from the target solution, T_j can be selected by the decision maker which representing his view to the problem. He can also select T_j as the ideal point $F_j(x^*)$. Non-dominated Pareto front are generated by parametrically varying the weights and solving the resulting problems. For over attainment of the desired goals, the smaller weighting coefficient is associated with the less important objectives.

iv. Step Method

The step method is one of the first interactive methods introduced for multi-objective optimization[19]and it was developed for MONLP problems[20]. The problem can be tackled through two phases:

Phase I: the “distance” of each non-dominated solution from the ideal solution F_j (x *) is determined. The alternative with the minimum distance (eq. 7) is selected as the compromise solution between conflicting objectives:

Minimize D .... (8)

s.t.

$W_j[F_j(x^*)-F_j(x)] \le D$; j=1,2,...,k …………..... (9)

In addition to equation (2) above.

Where $Wj= \alpha_j/\sum_{j=1,\ 2,\ldots,k}(\alpha_j)$, with $\alpha_j= [F_j\ (x^*) - \min F_j\ (x)]/ F_j\ (x^*)$ that represent the relevance of the deviation of the generic non-dominated solution from the ideal solution F_j (x*).

Phase II: the Compromise solution is presented to the decision maker, who compares its objective with the ideal one. If F_p (x) is satisfactory, but F_j (x) is not,(for j=1,2,...,k and $j \ne p$), the decision maker must relax the satisfactory objective F_p (x) enough to allow an improvement of the unsatisfactory F_j (x). If ΔF_p (x) is an acceptable amount of relaxation, the feasible region is modified in the next iteration cycle and anew solution is obtained. Figure 1 shows the flowchart of step method algorithm.

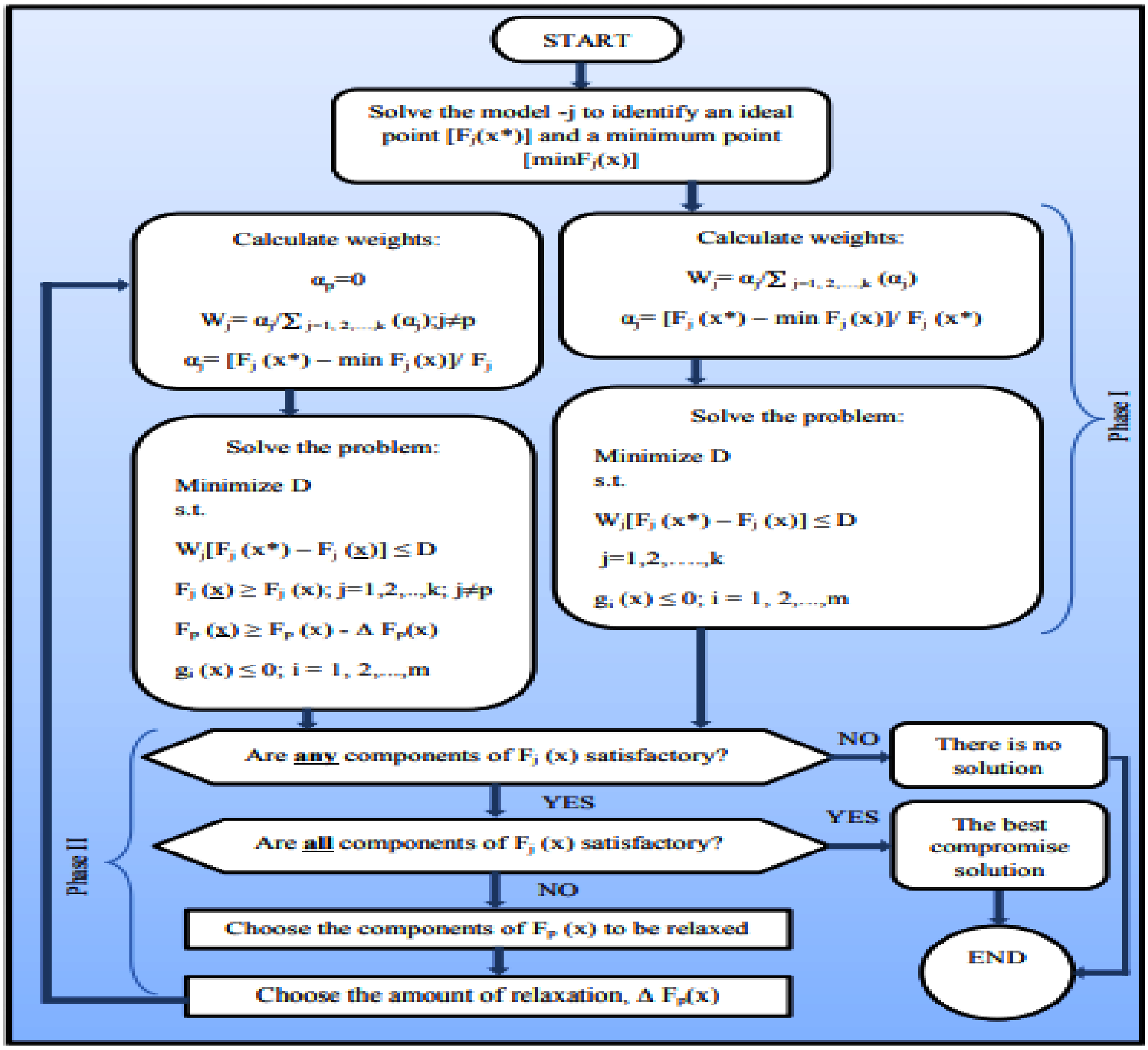

Fig. 1: Flowchart of Step method

5. MOSUL RESERVOIR (case study)

The Mosul Reservoir is one of the most important water resources projects in Iraq. It is located on the upper Tigris River, about 55 km northwest of the city of Mosul, at latitude 36º37'44"N and longitude 42º49'23"E figure 2. The maximum operational storage capacity (11110 MCM) and the dead storage (3000 MCM). The project is commissioned in July 1986 [21]. The Mosul Reservoir system was originally designed to serve several competing operational purposes over the available storage [1], among them are: Supplying irrigation requirements for three main irrigation projects. i. e, Al-Jezira North, East and South projects, The total agricultural area is 332,500 hectares, with a total discharge of the main canals around 230 m3 / sec [22].It is also of concern that Regulating the supply of water from the reservoir to facilitate hydropower generation. The reservoir has four penstocks/tunnels leading to turbines; with maximum generation capacity of 750 MW [1] and [21].

The observed time series of inflow into the reservoir over 30 years(1989-2019) is shown in figure 3.

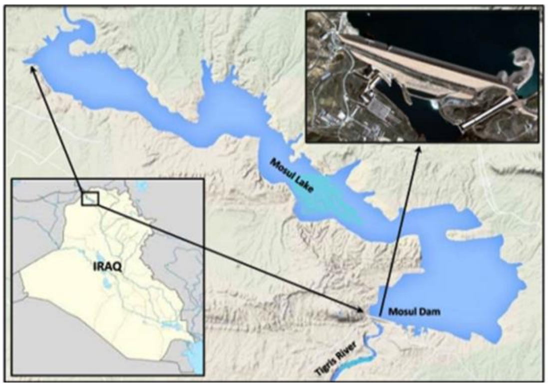

Fig. 2 Location of Mosul dam

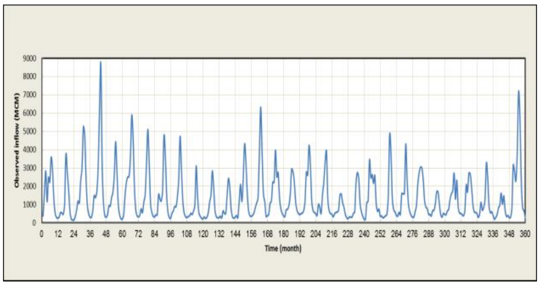

Fig. 3: The observed monthly inflow in to Mosul reservoir over the period 1989-2019

Figure4shows the schematic representation of Mosul reservoir system where the water is provided for the three projects directly from the lake. While electricity is generated from releases to the downstream. It is not recommended to generate electricity when the release is less than (120 m^3 / sec) in order to preserve the integrity of the turbine. In this case water is usually released through the bottom-outlet. In the case of large releases spillway can be implemented [21]. It is clear that the objectives for irrigation and that for power generation are competing objectives, in which increasing the value of any of them leads to a decrease in the value of the other.

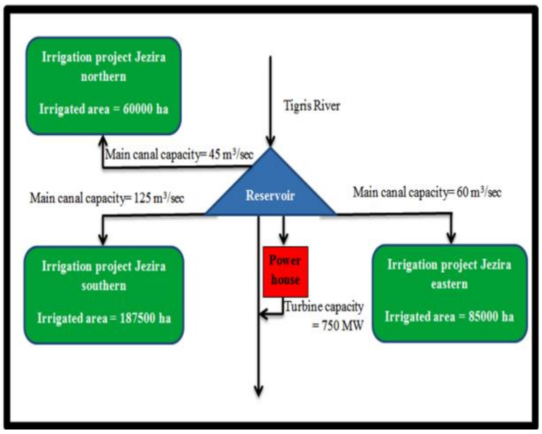

Fig.4 Schematic representation of multipurpose Mosul reservoir system

6. MULTI-OBJECTIVE MODEL FORMULATION

The multi-objective model is formulated for the operation of the reservoir based on a monthly time scale. The objectives are to provide the maximum sum of monthly water allocated for irrigation (Z) and to maximize the total annual electrical energy production (E).

Mathematically speaking and at the same time:

Maximize $Z = \sum_{i=1}^{12} I_i$.................. (11) Maximize $E = \sum_{i=1}^{12} 2725 *10^{-6}* R_i H_i \eta$…... (12)

Subject to the following constraints

$S_{i+1} = S_i + Q_i - I_i - R_i - E_i + Rn_i - O_i$………. (13)

$S_{min} \leq S_i \leq S_{max}$ ……..……….(14)

$I_{min} \leq I_i \leq I_{max}$……………. (15)

$R_{min} \leq R_i \leq R_{max}$…………….(16)

To calculate R_{max} discharge relationship in intakes is used:

$R_{max} = Cd*A*\sqrt{2*g*H_i}$ ……………. (17)

Where:

Z =The total volume of water diverted for irrigation during the year.(Mcm)

I_i= Average diversion for irrigation during month i.(Mcm)

E = The total energy generated during the year.(GWhr)[14].

R_i= Average release for hydropower during month i.(Mcm)

H_i= Average head of water above the turbine level in month i and is expressed as a nonlinear function of the average storage during that the month .(m)ŋ=Power plant efficiency and assumed to be 0.8 [21].

S_i= Final storage volume at reservoir during month i. (Mcm)

Q_i =Average inflow to the reservoir during month i. (Mcm)

E_i= Average evaporation from the reservoir during month i.(Mcm)

Rn_i= Average rainfall over the reservoir during month i(Mcm)

O_i=Overflow from the reservoir during month i.(Mcm)

I_{min}= Minimum demand for irrigation in month i.(Mcm) I_{max}=Maximum demand for irrigation in month i. (Mcm) R_{min}=Mosul reservoir downstream requirements in month i.(Mcm) R_{max} =Total capacity of the power plant during any moment in month i.(Mcm)Cd =The flow coefficient which is equal to 0.6. A= The cross section area of penstocks. (m^2) g=The acceleration due to gravity.(m/sec^2)

The mathematical model proposed here is using Genetic algorithms which belong to the family of artificial intelligence and specifically to evolutionary algorithms. The available Genetic algorithm was used in the (MATLAB) software.

7. RESULTS AND DISCUSSION

the results obtained from the model (equations (11) through (17))were evaluated using the four interactive schemes proposed in the plan formulation above .Table1 enumerates the details of weighting method for nine cases by giving multiple weights to the two objectives, multiple results were obtained through which the Pareto interface is constructed, (see Figure 5), from the results, for instant, case 6 was selected with equal priority for the two objectives, i.e. are 50%for irrigation and 50% for hydropower generation, and the optimum point was (5906, 1600) MCM and MWhr respectively. The operation policy on monthly basis is presented in Table 2 below. While figure 6 depicts those operating policies graphically.

Table 1:Optimal results for weighting method of Case 1 through Case 9

Alternative	W_1	W_2	Irrigation(MCM)	Energy(MWhr)
Case 1	1	0	7154	1402
Case 2	0	1	5007	1749
Case 3	0.1	0.9	5830	1614
Case 4	0.2	0.8	5864	1604
Case 5	0.4	0.6	5897	1601
Case 6	0.5	0.5	5906	1600
Case 7	0.6	0.4	5929	1598
Case 8	0.8	0.2	5931	1597
Case 9	0.9	0.1	5966	1592
Ideal point			7154	1749

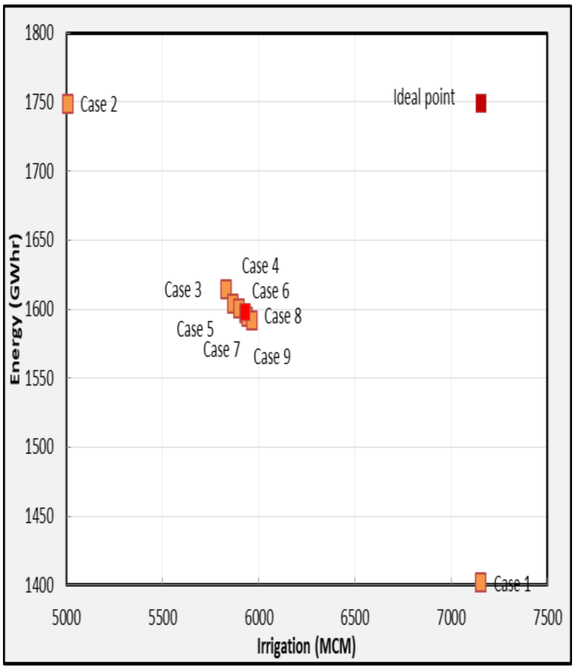

Fig. 5:Pareto frontfor nine cases (Weighting method)

Table 2:The average reservoir storage, release rate and energy rate(Weighting method-case 6)

Month	Storage (MCM)	Release irrigation (MCM)	Release hydropower (MCM)	Energy (GWhr)
Oct	6784	417	387	53
Nov	6513	417	337	45
Dec	6575	417	337	45
Jan	6949	417	337	46
Feb	7590	417	337	47
Mar	8799	417	369	54
Apr	10156	441	2217	339
May	10841	595	2070	326
Jun	11002	581	693	110
Jul	10720	596	610	96
Aug	9979	595	737	112
Sep	8265	595	2278	327
Total		5906	10708	1600

Regarding the implementation of the constraint method, the model was optimized to obtain the objective function of the demand for irrigation. A set of ten cases is determined by changing the lower limits of the hydroelectric production to obtain a set of optimal solutions through which the Pareto interface is formed as shown in (Table3). For example, optimal solution of case 7 was (6236, 1555) in which around 88% of irrigation and energy generation were obtained. Those results are summarized in Table4.

Table3:Optimal results for constraint method of Case 1 to Case 10

Alternative	L_i	Irrigation (MCM)	Energy (MWhr)
Case 1	1740	5078	1740
Case 2	1700	5262	1700
Case 3	1650	5480	1650
Case 4	1630	5748	1630
Case 5	1600	5917	1600
Case 6	1575	6130	1575
Case 7	1550	6236	1555
Case 8	1525	6286	1525
Case 9	1500	6483	1500
Case10	1450	6789	1450
Ideal Point		7154	1749

Table4:The average reservoir storage, release rate and energy rate (Constraint method-case 7)

Month	Storage (MCM)	Release irrigation (MCM)	Release hydropower (MCM)	Energy (GWhr)
Oct	6784	417	387	53
Nov	6512	417	337	45
Dec	6574	417	337	45
Jan	6948	417	337	46
Feb	7579	417	358	50
Mar	8635	595	475	69
Apr	10214	596	1334	205
May	11043	595	2509	399
Jun	11043	577	580	92
Jul	10700	596	846	132
Aug	9811	594	801	121
Sep	8165	596	2076	297
Total		6236	10378	1555

As for as the goal-attainment method is of concern each non-dominant solution was determined from the ideal solution. Nine cases of multiple weights were selected to express the importance of the two opposing objectives to obtain a set of optimal solutions for which the Pareto interface is constructed as shown in (Table5 and Figure 7). Case 5 was selected, with equal weight for both goals as and the optimums point was (6188, 1558).Those results are summarized in Table 6.

Table5: Optimal results for goal-attainment method of Case 1 to Case 9

Alternative	W_1	W_2	Irrigation(MCM)	Energy(MWhr)
Case 1	0.1	0.9	6051	1583
Case 2	0.2	0.8	6090	1577
Case 3	0.3	0.7	6132	1575
Case 4	0.4	0.6	6125	1569
Case 5	0.5	0.5	6188	1558
Case 6	0.6	0.4	6121	1568
Case 7	0.7	0.3	6141	1569
Case 8	0.8	0.2	6235	1549
Case 9	0.9	0.1	6363	1528
Ideal Point			7154	1749

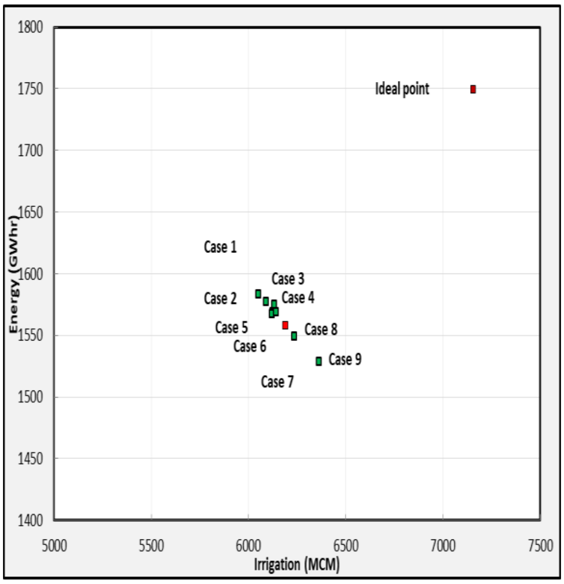

Fig. 7:Pareto front for nine cases(Goal-Attainment method)

Table6:The average reservoir storage, release rate and energy rate (Goal-Attainment-case 5)

Month	Storage (MCM)	Release irrigation (MCM)	Release hydropower (MCM)	Energy (GWhr)
Oct	6768	449	388	53
Nov	6467	423	358	48
Dec	6515	419	337	45
Jan	6886	422	337	46
Feb	7515	435	338	47
Mar	8691	498	337	49
Apr	10160	588	1794	275
May	10936	586	2173	344
Jun	11012	595	757	120
Jul	10791	591	412	65
Aug	10097	592	849	130
Sep	8297	589	2346	337
Total		6188	10426	1558

The step method is an interactive decision-making method whereby the Pareto interface is not drawn, but the optimal policy is selected by interacting with the decision maker. Weight of importance was calculated for the two contrasting objectives, the result was shows that irrigation requires w=0.6 while power is associated with w=0.4. The optimal solution phase come to be (6121, 1568).Table7 summarized the results obtained from step method.

Table7:The average reservoir storage, release rate and energy rate (Step method)

Month	Storage (MCM)	Release irrigation (MCM)	Release hydropower (MCM)	Energy (GWhr)
Oct	6770	447	387	52
Nov	6477	429	337	45
Dec	6532	422	337	45
Jan	6901	422	337	46
Feb	7532	433	337	47
Mar	8662	489	440	64
Apr	10113	595	1729	264
May	10935	596	2127	337
Jun	11056	596	700	112
Jul	10835	596	465	73
Aug	10124	500	918	140
Sep	8316	596	2379	342
Total		6121	10493	1568

The analyses the results reveal that the constraint method has a better converges to the Pareto front than weighting method and goal-attainment method , this is because constraint method is restricted one of the objectives to a certain value chosen by the decision maker. Thus, provide the DM with more flexibility in selecting the required solution among the available wide spectrum of solutions. On the other hand, the weighting method is suffering from the fact that the Pareto surface should be convex, however one cannot guarantee this property in the real time planning situations. The goal-attainment method has one drawback due the fact that the solutions obtained from this method are always limited to the middle zone of the Pareto surface as the method is always seeking the minimum distance from the ideal point to the Pareto surface. When it comes to step method, no Pareto surface can be obtained from this procedure so the comparison with the above three schemes is not sound as no bases for comparison is available. Figure8shows that step method has only single point laying on Pareto surface.

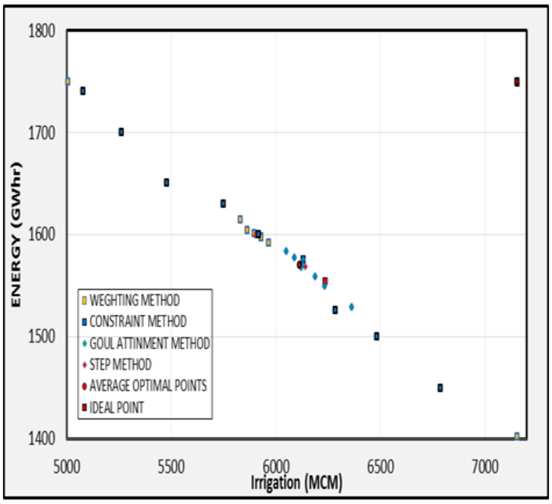

Fig. 8: Pareto front generated by different methods used in the study

Though the results obtained from the application of weight method, constraint method, goal attainment method and step method reveal that they are somewhat different, and the method of constraint seems to be the most likely to be selected by the DM, however, the decision maker still has some doubts about the feasibility of this result, and the confusion in the decision-making process is still overwhelming the situation. Accordingly, the researchers suggest a compromise solution in which the ***average*** value of the solutions emerged from the four methods applied can be adopted as the most prefer solution (6113, 1570). This solution and from the view of the authors would be the most likely welcomed by the decision maker, because it has the minimum subjectivity in the selection process. After that, the solution must be practically reflected on the policy of operating the reservoir, so a reverse calculation was performed and the amount of monthly releases of the Mosul Reservoir was calculated, by setting those average values as equality constraints in the goal attainment method in which eventually leads to the optimal operation policy satisfies the target (6113, 1570). It was also considered informative to calculate the monthly average generated energy over the period (1989-2019). Surprisingly, the coincidences of those patterns obtained by the optimization method and the averaging method was almost perfect. Figure 9 depicts this coincidence. Moreover, the monthly average real time energy generated from Mosul reservoir over the same period was also compared with above two as shown in figure 9 below (in green). Again the agreement is good in terms of the patterns that the energy generation process have been taken, The main reason that actual energy generated curve is laying above the two other curves is because there was no actual diverted water for irrigation being made for the considered period.

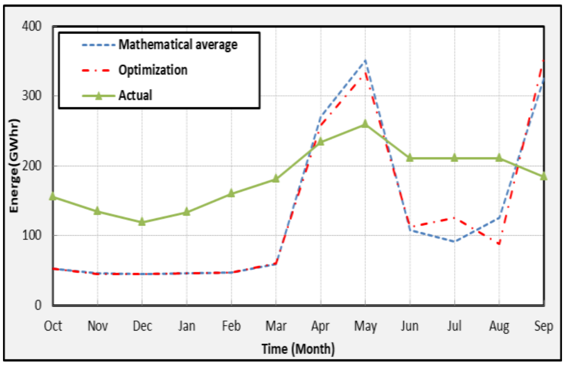

Fig. 9: Mosul reservoir average monthly energy generated (averaging, optimization methods and actual generation).

The operating policies in terms of storage and releases are summarized in Table 8.

Table8: Operating policies in terms of storage and of Mosul Reservoir based on achieving the goal of 6113MCM for irrigation and 1570 Gw-hr for energy generation annually for the given conditions of inflow.

Month	Storage (MCM)	Release irrigation (MCM)	Release hydropower (MCM)	Energy (GWhr)
Oct	6783	419	387	53
Nov	6508	422	337	45
Dec	6567	420	337	45
Jan	6938	420	339	46
Feb	7573	421	338	47
Mar	8671	587	417	61
Apr	10106	594	1688	258
May	10962	595	2102	333
Jun	11099	588	705	112
Jul	10710	596	804	126
Aug	10018	459	581	88
Sep	8358	592	2466	355
Total		6113	10501	1570

8. CONCLUSIONS

Multi-objective analysis using genetic algorithms is found to be an efficient methodology in allocating the optimal solution in an environment involving conflicting objectives. The current study includes the application of three methods of solution which are widely accepted among multi objective analyses community in tickling such kind of problems. These are weight, constraints and goal attainment methods. Multi-objective analyses do not yield single optimal solution, rather they are more useful at identifying the trade-offs among conflicting non-commensurable objectives. Typically, multi-objective analysis yields a set of non-dominant solutions called the Pareto Set in order to enable the decision-maker to choose the most preferred solution.

Additionally, another method called (Step method) has also been used. This method is characterized to having a single solution rather than a surface. The analysis showed that the constraints method surpasses its counterparts in terms of obtaining more reliable solutions in allocating water to the two specific conflicting purposes of Mosul reservoir over those solutions emerged from weight method and goal attainment method. This probably because it does not require that the space containing the feasible solutions should be convex as it is considered prerequisite in the weight method. On the other hand, the solutions obtained from the goal attainment method are usually limited to the central part of the Pareto surface, as this part is most likely containing the minimum distance to the ideal point from Pareto surface. Thus, allows the decision-maker (the most important partner in the planning and decision making process) to reflect his vision on the selection process by imposing it as a binding constraint in the formulation of the mathematical model. The results reveal differences in the solutions obtained from the four proposed methods, however, the decision maker might be still in confuse in how to select the most best one among them. That is why this study suggested to adopt the average value of the four solutions i.e (6113, 1570) as a compromise solution. The researchers believe that this solution has a good chance to be selected by the decision-maker, given that it contains the least possible degree of subjectivity inherent in this sort of decision making process.

It was assumed that the decision maker is convinced and satisfy with proposed average value of the obtained solution, consequently, it was required to perform the calculations in a reverse order to obtain the optimal operation policy for the Mosul reservoir, which included an annual diversion of 6113 million cubic meters of water for the purpose of irrigation and to generate 1570 Gw-hr annually under a given inflow conditions into Mosul Reservoir.

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التخطيط واتخاذ القرار تحت ظروف اللاتأكدية
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الملخص

تضمنت الدراسة الحالية عملية اتخاذ القرار المناسب تحت ظروف اللاتأكدية تحليلا رياضيا لتشغيل خزان سد الموصل بشكل امثل وقد سعت سياسة التشغيل هذه لتحقيق هدفين متناقضين هما تحويل الماء من الخزان لأغراض الري واطلاق الماء منه لغرض توليد الطاقة الكهرومائية. استخدمت اربع طرق للحل وهي: طريقة الاوزان ، طريقة المحددات ،طريقة بلوغ الهدف، بالإضافة الى طريقة الخطوة اشارت النتائج التي رشحت من تطبيق هذه الطرق الى تقارب في القيم المحسوبة, فقد توصلت الطريقة الاولى الى ان الحل الامثل هو تخصيص (تخصيص 5906 مليون متر مكعب للري و توليد 1600 ميكا واط-ساعة من الطاقة الكهرومائية)و(6236, 1555) و(6188, 1558) و(6121,1568)على التوالي. اقترح الباحثان حلاً وسطياً يتمثل باعتماد معدل الحلول (6113, 1570). ان هذا الحل سيكون على الارجح محل ترحيب من قبل صاحب القرار لتضمنه اقل حد ممكن من الذاتية المتأصلة في هذا النوع من التخطيط .

الكلمات الداله :

صنع القرار, تحليلات متعددة الأهداف، اللاتأكدية, تشغيل الخزانات.