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Optimal Allocation of Water Resources for the Operation of Multi-Objective Reservoir

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ABSTRACT

A multi-objective model was developed to achieve a fair and acceptable allocation of Mosul dam reservoir. The model is aimed to maximize hydropower generation and provide the maximum water irrigation requirements for Al-Jazeera Northern Irrigation Project (ANIP) for three scenarios of reservoir inflow (wet, normal and dry seasons). The optimal results of Pareto front demonstrated the efficiency and success of multi-objective genetic algorithms (MOGA) to achieve fair and acceptable allocation of available water resources in multi-objective reservoirs. In Decision making method, seven distinct points were prepared that depend on the goal of allocating water to the AINP. Using these points, the amount of water allocated for irrigation is gradually increased, and values corresponding to the amount of the hydropower generation goal are found for each scenario. The results of the decision-making process for the seven identified points showed that the balance point can be considered point 7 as it has the possibility of allocating water to irrigate the three stages of ANIP with an increase in hydroelectric power generation for the three seasons by (26.96, 8.42, and 0.22) % respectively. This means that the project can be fully operated even in the dry season. Therefore, those managing persons who are responsible for the water resources of the Mosul Dam must reconsider the water allocation plans currently in place.

Keywords:

Allocation of water resources; multi-objective optimization; multi-objective genetic algorithm; Decision Making.

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1. INTRODUCTION

In Iraq, water resources crisis is worsening due to water reduction of main Iraqi rivers (Tigris and Euphrates), and the hydrological effects of climate change, in addition to low efficient management and planning for allocation of water resources [1-3]. These have led to the expansion of desertification and the succession of sand storms, that reached 283 storms per year [4]. The above situation leads to renewed talk about the necessity of operating the irrigation projects that are out of service, as a result of the limited amounts of available water [1]. Al-Jazeera Northern Irrigation Project (ANIP) that is located in Nineveh Governorate in Iraq is one of the important projects that can be reoperated as an attempt to use the alternative plans of developing agriculture and limit the encroachment of sand [5].

The Mosul Dam Lake is the main source of water supply to the ANIP [6]. The Mosul Dam Reservoir is used for multiple purposes including flood control and development in each of fish wealth and tourism [7], but the main objectives that contributed to the design and construction of Mosul Dam Reservoir were to allocate water to meet the irrigation requirements of ANIP and hydropower generation, these two functions are competing operational purposes for the available storage of the reservoir [6] and [8].

The Mosul Dam water resources administrators strive to allocating water for the operation of the reservoir for only the purpose of hydropower generation and putting the ANIP out of service. This is an inefficient allocation, as it is necessary to determine how to allocate water resources fairly and acceptably for the purpose of generating hydroelectric power and irrigation at the same time. This is a problem that needs an urgent solution to ensure water and food security.

Fair allocation of water resources is very important for the optimal allocation of water resources [9]. Such as the right to use water resources equally within the basin and distribute economic benefits. It is also important to mitigate conflicts over water consumption between rural and urban areas. As a result, Fair allocation aims to achieve a balance in multi-purpose water consumption such as hydropower, domestic needs, industry and agriculture. Thus, Precise and perfect plans are in demand in order to supply water with high reliability and follow certain allocation priorities. Besides, this problem of optimal water resource allocation is usually characterized by being multi-objective, constrained, non-linear, high-dimensional, complex and conflict [10] and [11].

Recently, many publications indicate that several multi-objective optimization methods have widely applied to solve problems of optimal allocation of water resources using Evolutionary algorithms, e.g. Fanuel et al. [12] had analyzed more than forty papers with limited application scope of multi-objective Evolutionary algorithm (MODE), non-dominated sorting genetic algorithm II (NSGA II) and MOGA to solve a multi-objective problem in water allocation, irrigation planning, cropping pattern and allocation of available land. The performance and results of these techniques will be discussed later.

Yan, et al [13], was able to build a general water allocation and simulation (GWAS) model, with the help of multi-objective computational schemes and two types of algorithms (NSGA-II algorithm and the rule algorithm), multi-objective reservoir operation, water use, environmental flow, and power generation are taken into account in the new model. The proposed model was applied to the Fuhe River Basin in China. A multi-objective water resource allocation analysis method was also be explained .

Khattab and Al-Mohseen [8] and [14] discussed the important issues related to planning and management of water resources systems when the decision-maker is uncertain of choosing a specific plan among a lot of available plans. The papers included a multi-objective mathematical analysis to operate Mosul reservoir in Iraq optimally. The proposed operating policy involved achieving two conflicted goals, namely diverting water from the reservoir to irrigate Al-Jazeera projects and secondly, releasing water for the benefit of power generation. Genetic algorithms (GAs) were used to find the required optimal solution. It was found that this optimization tool is efficient especially in the multi- objective analysis domain.

MSolgi et al. [15] proposed a model to manage the negative impact of water shortages under intermittent condition to the goals of increased the Water saving and reduced the interruption of Prepared Water. NSGA II is used for optimization. The model was applied in Sefidrud River (Iran).

Tang et al. [16] were created a new model of water resources with specific structure that based on fairness in addition to the risks. NSGA-III based method proposed an improvement on the ideal solution Choice strategy (ARNSGA-III) to figure out the results of the model. The application model was done in China (Wusu city) for three different proposed conditions of dry. The results proved the effectiveness and accuracy of the model's performance.

Hatamkhani et al. [17] have used the model of Water Elevation And Planning (WEAP) with optimization model of particle swarm (MOPSO) for the aims of maximum water supply of Iranian Karkheh River and the largest cultivated area.

Deng et al. [10] created a model for allocating resources of water to achieve equity and improve efficiency, with environmental river flow as a constraint. NSGA-II was applied to find a Pareto interface for a water resources allocation system, so that decision makers can develop a correct policy in planning and managing water resources. They applied their model in the catchment area of Han River in China.

Zhang et al. [18] in their research addressed the gap between the outlook of different views of water resources administrators by basing their thinking on the hybrid strategic whale optimization algorithm where they applied their model in Handan, China.

Faisal Bin Ashraf et al. [19] proposed a multi-objective framework for optimizing small hydropower plants (SHPs) to evaluate the balance between short-term losses in hydropower generation and the potential for recreational ecosystem benefits. The optimization process provides three outflow release scenarios. The framework has been applied and tested in the Kosinkyuki River in northeastern Finland.

Lu et al. [20] conducted research on multi-objective optimization configuration for water resources engineering (WRE) based on the MOGA. The current situation of water resources in a city in Jilin Province, China was evaluated and it was concluded that MOGA can allocate water resources reasonably and ensure the balance between water supply and demand.

The current study aims to explore possible solutions to achieve efficient, fair and acceptable allocation of water resources for Multi-Purpose Mosul Reservoir with two goals of generating hydropower and supplying irrigation water requirements for ANIP at multiple levels of inflow of Mosul reservoir considering wet, Normal, and dry seasons. This study may be enabling new ideas for multi-objective optimization of water resource allocation.

2. METHODOLOGY

A multi-objective optimization model is developed for fair allocation of available water of Mosul reservoir. The scenarios of inflow into reservoir represent for three seasons (wet, normal, dry) where selected and analyzed and then a MOGA has been applied, to find the set of possible solutions (Pareto front) for each scenario. Finally, Decision making process of the solutions are taking place by choosing distinctive points on Pareto front and comparing them with the actual operating case in order to choose one of the points as an equilibrium point between objectives in a fair and acceptable manner.

2.1 Multi-objective optimization

Multi-objective optimization involves multiple objectives that all need to be optimized simultaneously, even though these goals are often conflicting [21]. It should be noted that multi-objective analysis can generate a variety of compromise solutions, so simultaneous optimization for all goals does not always give the optimal value for each of the individual goals. In real, the set of compromise solutions that may lead to multiple optimal solutions is known as a Pareto front [22] where there is no solution in any way to improve any goal without affecting at least one of the other goals as in the case of our problem. The Pareto front is a different set of trade-offs between multiple objectives of an optimization problem [23].

The gradual shift from case of, simply using engineering-based optimization models, to a new case of, applying integrated water economic models, multi-objective decision-making, and conflict resolution models, all the above is an indication of promising changes in the applied traditional optimization model to derive operating policy for water storage systems [17]. A more comprehensive understanding of storage systems of multi-objectives, considering four cases: fair allocation of water, the values-goals-behavior of beneficiaries, improved abilities to forecast and plan for future impacts, where these cases can lead to more sustainable decisions to plan and manage storage systems with competing objectives [9] and [24]. Assuming that each objective $f_j(x)$ will be maximized, the model can be written as:

$$\max\ [f_1(x), f_2(x), f_3(x), ..., f_p(x)] \quad \ldots\ldots (1)$$

Subject to

$$g_i(x) = b_i \quad \ldots\ldots (2)$$

In this model x is a vector representing the decision variables, $x = [x_1, x_2, ..., x_n]$, $f_j(x)$, j = 1, ..., p, are the objective functions, and $g_i(x)$, i= 1, ..., m, are the constraints.

Although a range of Pareto Optimal solutions exist in practice, usually only one of these solutions is chosen. Therefore, to compare multi-objective optimization and single-objective optimization, there are at least two tasks that must be provided in multi-objective optimization: first, the optimization task of finding the Pareto front and second, the decision-making task of choosing the most preferred solution [25-26].

2.2 Multi-Objective Genetic Algorithms (MOGA)

The used MOGA can be described as a controlled elite genetic algorithm and is a substitute of NSGA-II Deb [27] [24]. An elitism MOGA favors individuals with a better fitness value (rank), simultaneously, MOGA favors individuals which can help increase population diversity even if they have a lower fitness value [28-29]. This is important to maintain population diversity in order to converge to the optimal Pareto front.

The MOGA was developed substitute of NSGA-II by adding the following conditions following [29-30]:

- The dominance: x_1 dominates x_2 when x_2 is inferior to x_1 for objective function f when:

Case 1: if $fn(x1) \le fn(x2)$ for each n.
Case 2: if $fm(x1) < fm(x2)$ for a few m.

A non-dominated solutions combined population $R_t = P_t \cup Q_t$ is formed. From between a set of values Pt is the set of values Q_t in P_t that are non-dominated in p_t.

- The rank: rank k individuals are dominated by individuals in rank k - 1 or lower.
- The crowding distance: distance is a sum over the dimensions of the absolute distances for the difference between the individual's sorted neighbors. For the value of the sorted objective function M at individual m, the distance value becomes D:

  $$D_m = D_{(m,M)} + (D_{(m+1,M)} - D_{(m-1,M)}) \quad \ldots\ldots (3)$$

The basic steps in the MOGA technique are to create a random initial population (p_t) of size N, with t=0. The population is then evaluated by performing non- dominant sorting and crowding distance sorting, and this is done by evaluating the objective functions (fitness) for classifying the rank of the population. The iterative process continues to select the new generation of population by the selection function from the current population, where the crowding distance measure is used as a separator in the selection process to achieve diversity in the population. It is important to clarify that we are using a binary tournament selection operator, and in this way the population P_{t+1} is generated. Genetic operations (crossover and mutation) are then used to generate a new population Q_{t+1}, and stopping criteria are also taken into account. If the previously specified maximum number of generations is reached. Which achieves a variety of non-dominant solutions, it is Pareto optimal solutions. Figure 1 shows a flowchart of the main steps of the multi-objective genetic algorithm.

2.3 Case Study

The Mosul Reservoir is located on the Tigris River near Mosul city, the second largest city in Iraq, at latitude 36º37'44"N and longitude 42º49'23"E as shown in figure 2. Mosul Dam construction was completed in 1984 and in spring of 1985 filling of reservoir began. The type of Mosul Dam is an earth dam with a length of (3650 m), and a height of (113 m) [2]and [6]. The spillway is on the east side of the dam which is controlled by five radial gates, the fuse-plug-controller is further to the east which is an emergency spillway, and the bottom outlet is in the west side of the dam and consists of two outlets with sectional gates [31]. The maximum operational storage capacity (11110 MCM) and the dead storage (2950 MCM) [2]. The Mosul Reservoir is an important water resource project in Iraq. It was ranked by the World Commission Dams as the Middle East's fourth largest dam in term of reservoir capacity [31].

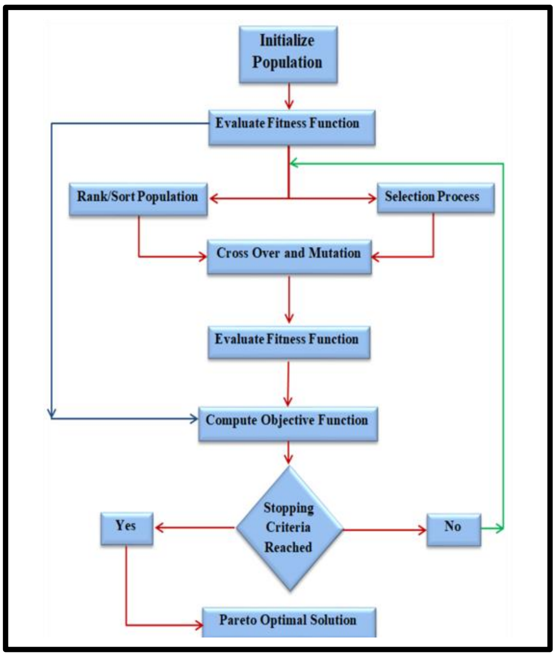

Fig. 1: Flowchart of Multi-Objective Genetic Algorithms (MOGA).

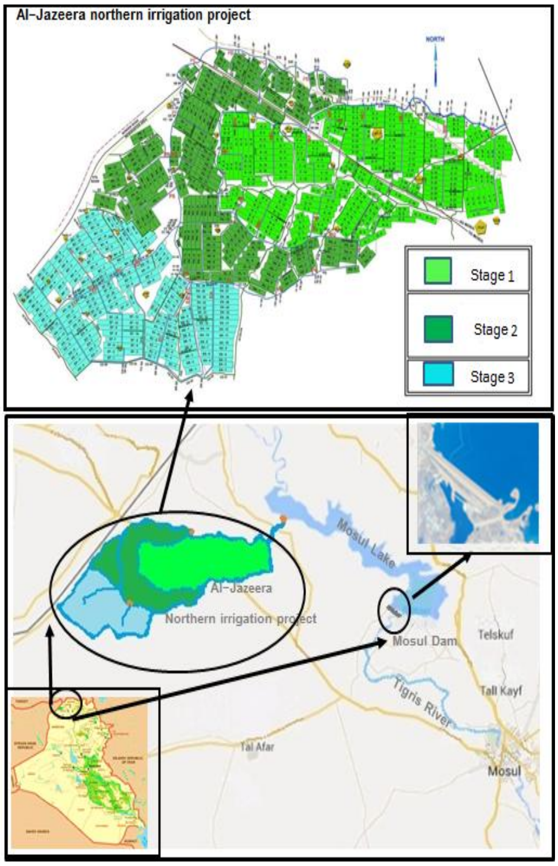

Fig. 2: Site of the Mosul Dam and Al-Jazeera northern irrigation project

The Mosul Dam reservoir is used for multiple purposes, the most important of which are:

1. Hydropower Generation

The hydropower station of Mosul reservoir (HSMR) is located at the toe of the dam on its west side. The power generation started in the 7^{th} of July in 1986. HSMR contains four Francis turbine generators of (193 MW) with total installed capacity of (750 MW) [8]. Behind the power station there are four surge tanks. The HSMR contributes a major share of Iraq's need for electrical energy.

2. Availability of Water Requirement for ANIP

ANIP is one of the vital government projects in Iraq and the most important main goals that contributed to the construction of the Mosul Dam. ANIP was implemented during the 1980s and actually entered service in (1992), and was operated at maximum capacity in (1994). Al-Jazeera northern irrigation project is located about (100 km) northwest of the city of Mosul. This project covers the lands located on both sides of the Baghdad-Mosul-Rabia railway line, starting from Uwainat until Rabia district and extending west to the Iraqi-Syrian border [32].

The project is supplied with water directly from the Mosul reservoir through the main pumping station to the main channel of the project. The main pumping station contains twelve submersible pumps, nine for water supply and three backup pumps. This station is considered as one of the only facilities in the world that was designed to be submerged in the water of the Mosul reservoir for most days of the year. The design discharge of the main channel is (45 m3/s) and its length is (58 km). The project lands consist of a plate-shaped plateau interspersed with Wadi al-Murr, which is considered as a natural drain for surface water drainage in this area, as shown in figure 2. The total area of ANIP is about (60,000 ha) and net area (58,700 ha) of agricultural land that is used in the production of many important agricultural crops such as wheat, beets, potatoes, cotton, and other crops [5][6] and [8].

The agricultural production can be increased by (123 percent) when using full operation of the project, equivalent to (100 percent) for winter crops and (23 percent) for summer crops. The project also provides thousands of job opportunities and contributes to achieving food security and community peace simultaneously. The ANIP consists of three stages [32].

i- The first stage

The first stage includes irrigating a total area of (25,000 ha) as shown in the figure 1 where the area covered by this stage is shaded in light green. It is irrigated through (13) sub-canals with a designed discharge (18 m^3/s), supplied with water from the main canal of the project. The first stage of land irrigation was designed and implemented using linearly moving sprinkler irrigation systems [32].

ii- The second stage

The second stage includes irrigating total area of (18,275 ha) as shown in the figure 1, where the area is shaded in dark green. Its lands are irrigated through sub-canals with a design discharge of (14.75 m^3/s), that supplied with water from the parallel canal with the following characteristic: the design discharge (27 m^3/s), and total length of (50 km). Surface irrigation system is used for this stage [32].

iii- The third stage

Its lands are irrigated by both the branch and the expansion canals with a design discharge of (3.25 m^3/s) and (9 m^3/s) respectively. Both canals are supplied with water from the parallel canal. Surface irrigation system is also used for this stage [5].

ANIP became out of service as a result of the difficult circumstances that Iraq went through during (2014-2015), after that, its canals and the rest of its facilities were subjected to major damage as a result of military actions.

In 2017, the International Food and Agriculture Organization (FAO) adopted the rehabilitation of ANIP in coordination with the Iraqi Ministry of Water Resources. the rehabilitation was divided into three phases. It appears that a serious step has been taken in this direction, and on May 29, 2022 an announcement was actually made completion of the rehabilitation of ANIP. Despite this, the ANIP is still out of service, as Iraqi water resources administrators and decision makers are concerned about the operation of the project and believe that the ANIP is no longer feasible due to the water shortage in the reservoir of Mosul Dam.

Iraqi water resources administrators preferred generating electrical power, in addition water requirements downstream should be met and protecting the river's water from wastage rather than activating ANIP. Hence, the idea of this study crystallized, as a model for optimal allocation of water resources was proposed that allocates all available water resources in the region to all of water users in a fair and acceptable manner. It must be taken into account that the different views of Iraqi water resources administrators regarding of economic and social feasibility. This model will also provide options for water allocation at multiple levels, providing a clear view to Iraqi water resources managers and decision-makers on the feasibility of partially or fully restarting ANIP.

2.4 Data

Although the observed inflow data of Mosul Dam is available from a period dating back to the beginning of the operation of the Mosul Dam, the inflow data of Mosul Dam was used for the last 10-years, which available for the period (2011-2021), on a monthly basis, as shown in figure 3. This period was selected due starting to gradually decrease the inflow by several reasons including: the impact of climate changes that began to appear in Iraq, in addition to the impact of the dams construction inside of Turkey on the course of the Tigris River heading to Iraq.

In this study, three scenarios of inflow of Mosul reservoir were used as shown in figure 4. These are:

- Scenario 1: Wet season is year (2018-2019).
- Scenario 2: Normal season is average years (2011-2021).
- Scenario 3: Dry season is year (2017-2018).

Regarding irrigation requirements, the data of the Dutch consultant (Ndeco) , according to which the ANIP designs were prepared for each stage based on monthly period, as shown in figure 5.

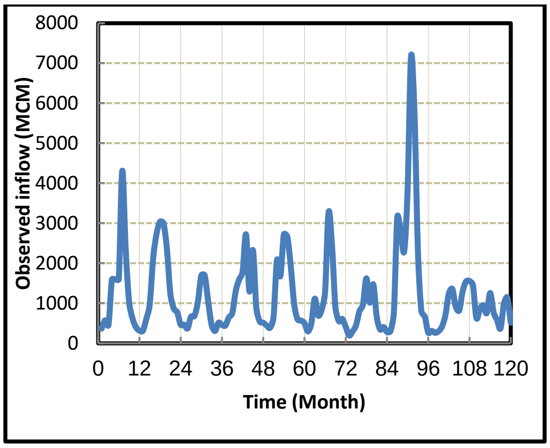

Fig. 3: The observed monthly inflow of Mosul reservoir

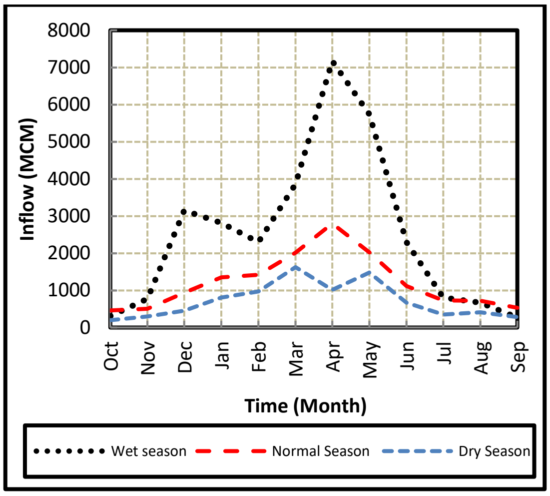

Fig. 4: The three scenarios of inflow of Mosul reservoir

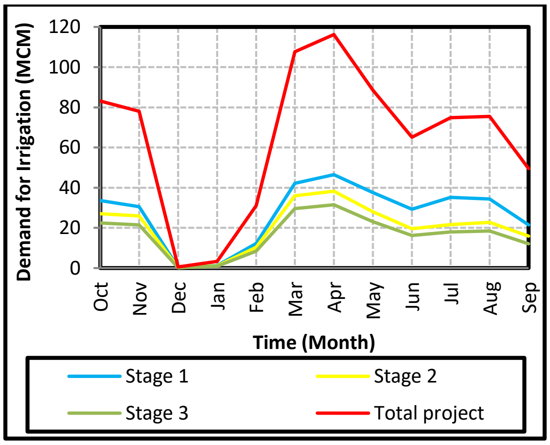

Fig. 5: the irrigation requirements for the three stages and their summation of ANIP

2.5 The working mechanism of the Mosul reservoir system

The working mechanism of the Mosul reservoir system (figure 6). This figure shows a schematic representation of the Mosul reservoir system. For Mosul dam, the electricity is generated by downstream releases, while the water is provided for ANIP directly from the lake that located upstream Mosul dam [6][8] and [32]. It is also possible to control the irrigation of the three stages of the project, i.e., It is possible to operate any combination of selected stages based on the amount of water available in the reservoir.

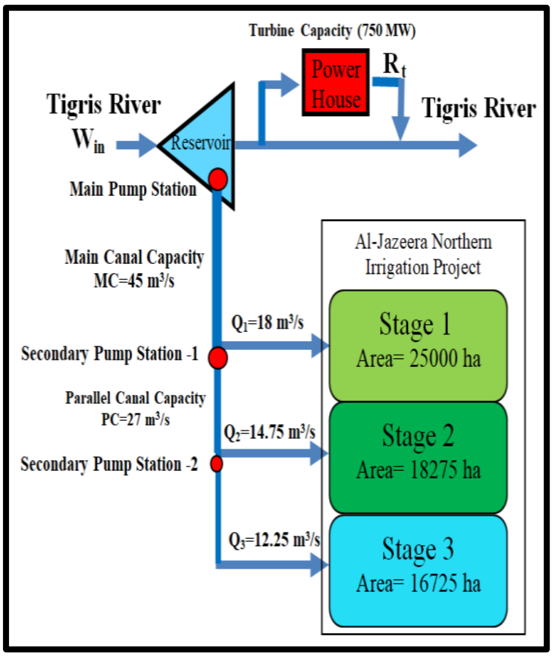

Fig. 6: schematic diagram of the Mosul dam and AINP

2.6 Multi-Objective Optimization Model

2.6.1 The objective Functions of this optimization model include:

The objectives are to maximize both of the total annual water allocated for irrigation of AINP (IR) and the total annual hydropower generation (HP). Mathematically, These two competing objectives of the system are expressed as follows:

$$\text{Max IR} = \sum_{t=1}^{12} Ir_t \qquad \text{.................. (4)}$$

$$\text{Max HP} = \sum_{t=1}^{12} \eta \; H_t \, R_t \qquad \text{………….. (5)}$$

Where IR is the sum volume of water diverted for irrigation during the year (MCM), ŋ is power plant efficiency and assumed to be 0.8, Irt is average diversion for irrigation during month t (MCM), HP is the sum hydropower generation during the year (MW), Rt is water release from power plant during month t (MCM) and Ht is head of water above the turbine level in month t and is expressed as a nonlinear function of the average storage during that the month (m), This relation can be approximated by the following formula[6]:

$$H_t = 15.24 + 0.01032 * \{(V_t + V_{t+1})/2\} - 4.525E\text{-}7 * \{(V_t + V_{t+1})/2\}^{2} \quad \ldots\ldots(6)$$

Where V_t is final storage volume at reservoir during month t, V_{t+1} is the initial storage volume at reservoir during month

2.6.2 The constraints of this optimization model include:

$$V_{t+1} = V_t + W_t - (Ir_t + R_t) + (Ra_t - Ev_t) - O_t \quad \ldots (7)$$

$$V_{min} \leq V_t \leq V_{max} \quad \ldots (8)$$

$$Ir_{min} \leq Ir_t \leq Ir_{max} \quad \ldots (9)$$

$$R_{min} \leq R_t \leq R_{max} \quad \ldots (10)$$

$$\sum_{t=1}^{12} (Ir_t + R_t) \leq W_{annual} \quad \ldots (11)$$

$$HP_{min} \leq \eta\, H_t\, R_t \leq HP_{max} \quad \ldots (12)$$

$$O_t = V_{t+1} - V_{max} \quad \ldots (13)$$

$$O_t \geq 0 \quad \ldots (14)$$

Where W_t is average inflow to the reservoir during month t, Ev_t is average evaporation from the reservoir during month t, Ra_t is average rainfall over the reservoir during month t, O_t is overflow from the reservoir during month t, Ir_{min} is minimum demand for irrigation in month t, Ir_{max} is maximum demand for irrigation in month t, R_{min} is Mosul reservoir downstream requirements in month t and R_{max} is total capacity of the power plant during any moment in month t, all the above volumes are measured in MCM. HP_{min} is the minimum amounts of power (MW), and HP_{max} is the maximum amounts of power (MW).

2.7 Evaluating the performance of MOGA

MOGA was applied to the used model (Multi-Objective Optimization Model) based design with Matlab2022a. Calculations were attempted for each MOGA application for the three scenarios (i.e. for each of the wet, normal and dry seasons), the goal is to ensure obtaining the optimal Pareto front using the parameters settings.

Four parameters were selected in this evaluation including: Number of Generation, Population size, Crossover probability, and Mutation probability. The selected parameter was changed, while the rest of the other parameters were fixed without change. Then the program was executed until the highest target value was reached, then the value of the selected parameter was recorded as the maximum final value. The same applies to the rest of the parameters.

In order to evaluate the performance of MOGAs for the three seasons in deriving the optimal water allocation for the Mosul multi-objective reservoir system, the same parameters settings were chosen in these algorithms for the three scenarios mentioned above as shown in Table 1. Due to the random nature of evolutionary algorithms, a maximum of 10 calculation attempts (run) were adopted to reach the optimal solution for each.

Table 1: parameter settings for MOGAs

Number of Generation	Population size	Crossover probability	Mutation probability
2000	300	0.9	0.02

2.8 Decision making method

In general, there are many trade-offs on the Pareto front. The decision-maker must determine the balance point between the improvement goals on the Pareto front that achieves a fair and acceptable solution for each goal. How to determine the equilibrium point is a very important issue, as explained by [23][24]and [33] as each of them followed a different method in determining the equilibrium point.

In this study, seven distinct points were prepared that depend on the goal of allocating water to the AINP, as in Table 2. Using these points, the amount of water allocated for irrigation is gradually increased, and values corresponding to the amount of the hydropower generation goal are found for each scenario.

Table 2: A points distinct depend on the goal of allocating water to the AINP

Points	Water allocation to (ANIP)	The irrigation requirements (MCM)
Point 1	The third stage	202.4
Point 2	The second stage	246.7
Point 3	The first stage	324.3
Point 4	The second stage and the third stage	449.2
Point 5	The first stage and the third stage	526.7
Point 6	The first stage and the second stage	571.1
Point 7	The first stage, The second stage and the third stage	773.5

To obtain the best choice among the seven points based on the choice of the decision maker (water resources managers) who prefers generating hydropower and meeting water needs downstream over other goals, the amount of actual hydropower generation produced by the decision maker was adopted and compared with the results of the objective function (Hydropower generation), the balance point is chosen that gives the hydropower generation goal value greater than the actual hydropower generation and at the same time allocates the largest amount of water for irrigation. This may be considered the most preferable solution.

3. RESULTS AND DISCUSSION

3.1 MOGA Results

This section includes too long sentence. The MOGA approach was applied to a multi-objective optimization model for the Mosul Reservoir System. This model aims to allocate fair and acceptable water for both providing irrigation water needs for ANIP and generating hydropower .

The MOGA results included finding the optimal Pareto front for the three inflow scenarios (i.e. for each of the wet, normal, and dry seasons) as shown in figures (7,8,9) respectively, which show that the set of solutions is well distributed along the Pareto optimal front for the three flow scenarios. Moreover, the set of solutions reflects the conflicting relationship between the two goals, as it turns out that the continuous increase in the amount of water allocated for irrigation is offset by a continuous decrease in the value of hydropower generation in the three seasons. These solutions can achieve a comprehensive vision of the two goals and provide new ideas to decision makers, depending on their degree of preference for the two goals, to make decisions more efficiently.

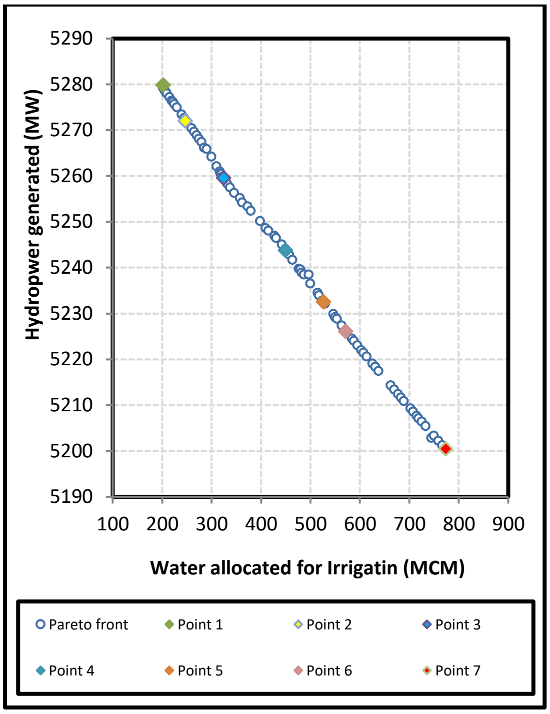

Fig. 7: The optimal Pareto front for Wet season

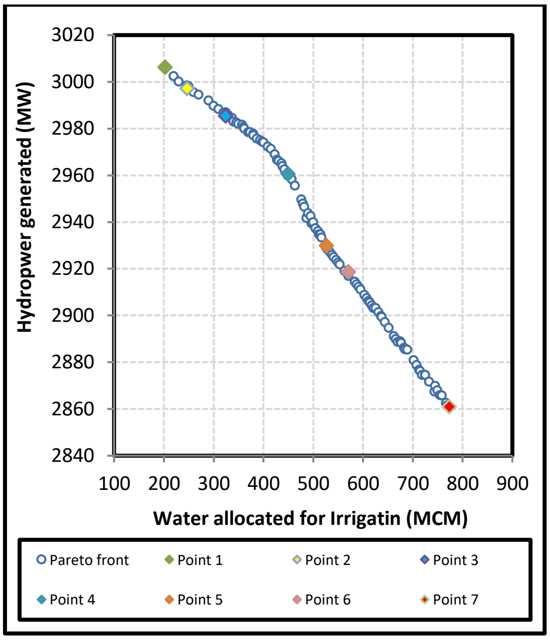

Fig. 8: The optimal Pareto front for normal season

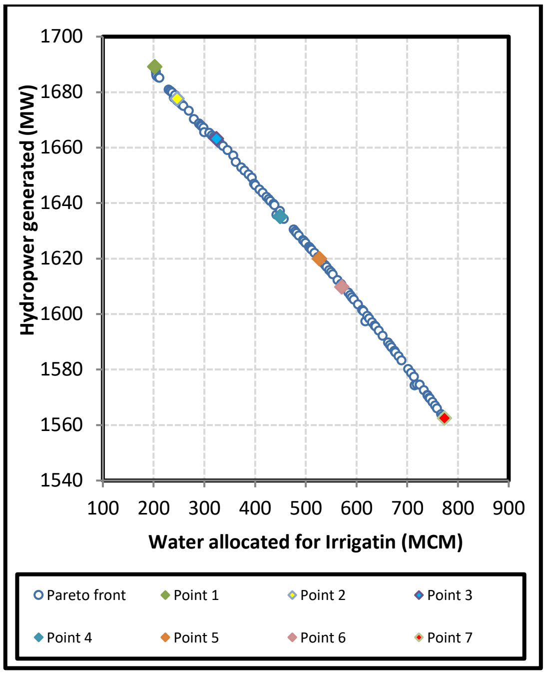

Fig. 9: The optimal Pareto front for dry season

3.2 Decision-making analysis.

The results showed the values of the seven points on the Pareto front for the three scenarios during the wet, average, and dry seasons, as shown in figures (7,8,9), where the coordinates of each of the seven points represent the allocation of water for irrigation and hydropower generation. Furthermore, the results in table 3 indicate the values for the above seven points and the goal's values for the actual operation of the Mosul reservoir for the three scenarios, respectively.

Table 3: Results of the seven points for allocating water and the actual operation of the Mosul reservoir.

	Irrigation MCM	hydropower generation MW		
Points	every season	Wet season	Normal season	Dry season
Points 1	202.43	5279.87	3006.24	1689.15
Points 2	246.78	5272.07	2997.19	1677.69
Points 3	324.33	5259.60	2985.44	1663.19
Points 4	449.21	5243.78	2960.68	1635.25
Points 5	526.76	5232.54	2929.93	1619.91
Points 6	571.11	5226.15	2918.67	1609.85
Points 7	773.54	5200.46	2860.99	1562.50
Actual	0.0	4096.00	2638.91	1559.08

To obtain the best choice among the seven points based on the choice of the decision-maker, the actual hydropower generation values were compared with the results of the objective function of hydropower generation for all points and for the three seasons to determine the balance point.

The results in table 4 showed the percentage increase in the values of the hydropower generation objective function over the actual hydropower generation values at the seven points and for the three seasons.

Table 4: the percentage increase of hydropower generation between the values of the objective function and the actual hydropower generation values at the seven points and for the three seasons

	Irrigation MCM	increase hydropower generation %		
Points	every season	Wet season	Normal season	Dry season
Points 1	202.43	28.90	13.92	8.34
Points 2	246.78	28.71	13.58	7.61
Points 3	324.33	28.41	13.13	6.68
Points 4	449.21	28.02	12.19	4.89
Points 5	526.76	27.75	11.03	3.90
Points 6	571.11	27.59	10.60	3.26
Points 7	773.54	26.96	8.42	0.22

Studying and analyzing the above results shows that the balance point is represented by point 7, this point has the possibility of allocating water to irrigate the three stages of AINP, with an increase in hydropower generation for the wet, normal and dry seasons reached (26.96, 8.42, and 0.22) % respectively, i.e. for dry season a slight increase over the actual hydropower generation was achieved. This means that the AINP can be fully operated even in the dry season.

For further clarification, the results were presented based on a monthly basis, as shown in Figure (10), which shows the monthly volume of water allocated for irrigation for the seven points. It should be noted that the design quantity of water allocated for irrigation was maintained depending on the capacity of the canals and the agricultural cycle during the three seasons. The figures (11,12,13) show the monthly hydropower generation for the seven points and the actual hydropower generation for the three scenarios.

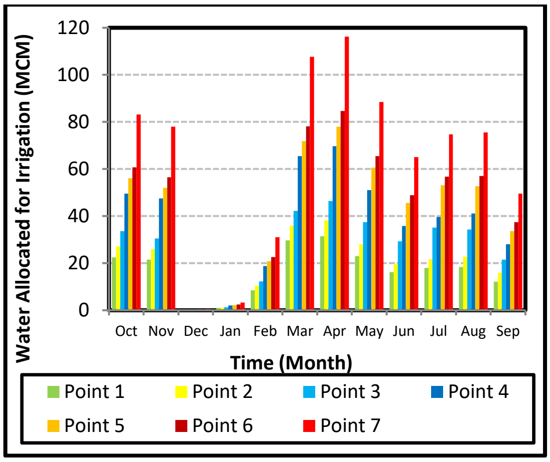

Fig. 10: The volume of water allocated for irrigation per month for the seven points.

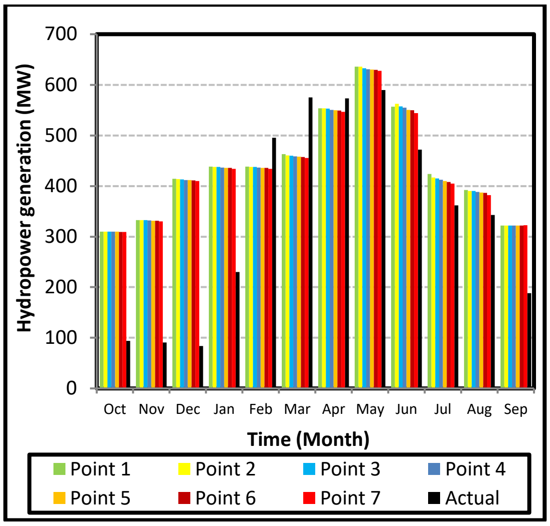

Fig. 11: water volume allocated for irrigation per month for the seven points for the wet season

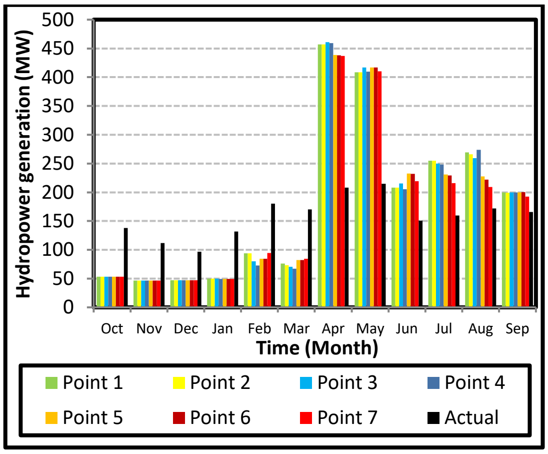

Fig. 12: The volume of water allocated for irrigation per month for the seven points for the normal season

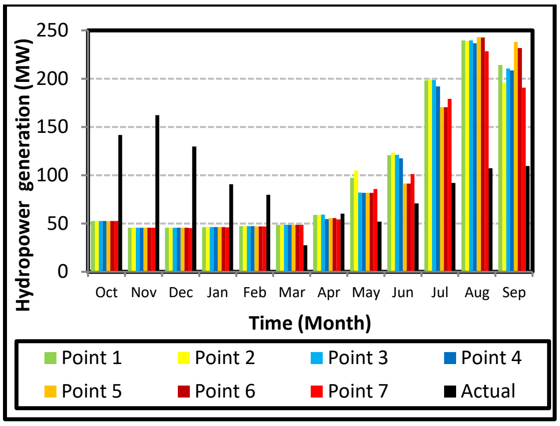

Fig. 13: The volume of water allocated for irrigation per month for the seven points for the dry season

4. CONCLUSIONS

Currently, Iraq suffers from an increasing shortage of water resources, deterioration of agricultural lands, and the expansion of desertification. This requires effective and competent management of limited water resources.

This study demonstrated the efficiency and success of MOGA to achieve effective, fair and acceptable allocation of available water resources in multi-purpose reservoirs. The main advantage of the MOGA approach is finding several optimal solutions of the Pareto front in a single process of calculations. It is an effective and attractive method that helps in achieving a comprehensive vision of the goals and provides new ideas to decision makers according to their degree of preference for the goals to make decisions more efficiently.

The optimal results of the Pareto front are shown for the three scenarios that generate options for water allocation at multiple levels, providing a clear vision for Iraqi water resources managers and decision-makers on the feasibility of partially or fully restarting ANIP.

The results of decision-making analysis for the seven points that were identified showed that the balance point can be considered point 7, as it has the possibility of allocating water to irrigate the three stages of AINP with an increase in hydropower generation for the wet, normal and dry season reached (26.96, 8.42, and 0.22) % respectively, i.e. for dry season a slight increase over the actual hydropower generation was achieved. This means that the AINP can be fully operated even in the dry season. Therefore, those responsible persons for managing the water resources of the Mosul Dam must reconsider the implementation of the water allocation plans currently in place, and not just focus on hydropower generation and ignore the fairness of water distribution to achieve an effective, fair and acceptable allocation of water resources to the Mosul Dam multi-purpose reservoir and ensure water and food security in the region.

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التخصيص الأمثل للموارد المائية لتشغيل الخزان متعدد الأغراض

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المستخلص

في هذه الدراسة تم تطوير نموذج متعدد الأهداف لتحقيق تخصيص عادل ومقبول للموارد المائية لخزان سد الموصل الذي يهدف الى تعظيم توليد الطاقة الكهرومائية، وتوفير الحد الاقصى من متطلبات مياه الري لمشروع ري الجزيرة الشمالي (ANIP) لثلاث سيناريوهات من التصاريف الداخلة الى الخزان (اي لكل من الموسم الرطب والمتوسط والجفاف). اظهرت نتائج جبهة باريتو المثلى كفاءة ونجاح الخوارزميات الجينية متعددة الاهداف (MOGA) لتحقيق تخصيص عادل ومقبول للموارد المائية المتاحة في الخزانات متعددة الأهداف. في عملية اتخاذ القرار تم إعداد سبع نقاط مميزة تعتمد على هدف تخصيص المياه لـ AINP. باستخدام هذه النقاط، يتم زيادة كمية المياه المخصصة للري تدريجيًا، ويتم العثور على قيم تتوافق مع كمية هدف توليد الطاقة الكهرومائية لكل سيناريو. اظهر تحليل اتخاذ القرار للنقاط السبعة التي تم تحديدها انه يمكن اعتبار نقطة التوازن هي النقطة 7 حيث ان لها امكانية تخصيص المياه لري المراحل الثلاثة لـ ANIP مع وجود زيادة في توليد الطاقة الكهرومائية للمواسم الثلاثة بنسبة (0.22، 8.42، 26.96) على التوالي. وهذا يعني امكانية تشغيل المشروع بالكامل حتى في موسم الجفاف. لذلك يجب على القائمين على إدارة الموارد المائية لسد الموصل اعادة النظر في خطط تخصيص المياه المتبعة حاليا.

الكلمات الدالة:

تخصيص الموارد المائية، التحسين متعدد الأهداف، خوارزمية وراثية متعددة الأهداف، صنع القرار