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RESEARCH ARTICLE

OPTIMIZATION MODEL USING HARMONY SEARCH ALGORITHM BASED ON HYDROPOWER GENERATION FOR TWO OF SINGLE STORAGE SYSTEMS

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ABSTRACT

There are two aims of this study. The first is to formulate and evaluate an optimization model for the operation of Mosul reservoir using the Harmony Search Algorithm (HSA) based on maximizing annual hydropower generation. The second one is to identify the optimal operation policies of the Bekhmah reservoir by adopting the HAS model that was formulated previously for the Mosul reservoir. Mosul reservoir is located on the Tigris River, while Bekhmah reservoir is proposed to be constructed on the Greater Zab River. The HSA model, that was created for Mosul reservoir, was evaluated under 10 scenarios of real monthly operation, which represent ten years with meeting all the constraints of operation. The results indicated that the annual hydropower generation using the HAS model of Mosul reservoir was better than real operation through the ten scenarios. According to this result, the HSA was applied to specify the optimal operation policies for the Bekhmah reservoir using three modes of annual flow (minimum, average, and maximum). These operation policies aimed to address water storage requirements for the water needs of the population, irrigation, and environmental requirements and ensure the availability of theses quantities of water in the storage system during the early three months of the following year. This study indicated the effectiveness of the HAS model to determine the optimal releases from any storage system by considering the hydrological aspects of that system.

KEYWORDS

Optimization model. Harmony Search Algorithm. Hydropower generation.

1. INTRODUCTION

Water resources are essential for maintaining human life as well as for many hydrological aspects of developmental progress. With population growth, economic development, and social progress, the demand of water was increased. To address this challenge, the operation schedule of reservoirs should upgrade according to those hydrological aspects, in addition to climate changes. As knowing, the operation schedule of each water storage system was formulated by adopt the concept of specific optimal technique. The Harmony Search Algorithm (HSA) considered a modern and new technique used to determine the optimal policies in the operation of water storage systems.

These studies have application of the HSA in various optimization problems related to water resource management and hydropower generation. Introduced the HSA as a heuristic optimization method inspired by music (Geem et al., 2001). They applied this algorithm to address water distribution network problems, achieving optimal designs for such networks. used the HSA for engineering optimization, demonstrating its efficiency in solving engineering challenges with continuous design variables, outperforming other algorithms in various scenarios (Lee & Geem, 2005). Woo Geem, n.d. applied the HSA to optimize the operation scheduling of a multi-dam system, surpassing a genetic algorithm in discovering multiple high-benefit solutions for irrigation and hydropower production. Previous study focused on parameter adjustment within the HSA, dynamically adapting parameters for improved accuracy and recall, surpassing traditional genetic algorithms (Kumar et al., 2012). Others applied HSA to address optimization challenges in a 24-hour quad storage system for water release into irrigation dams, contributing to a better understanding of system operation and optimization (Kougias & Theodossiou, 2013). A study optimized the flood control performance of the Narmab reservoir using HS, demonstrating its efficiency in managing floods and operating the reservoir on a monthly basis (Bashiri-Atrabi et al., 2015). A study employed the HAS to improve the construction and operation of the Bakhtiyari dam and associated power plant project, obtaining simultaneous solutions for design and operation variables (Mousavi et al., 2017). Findings merged the Cellular Automata with HSA for effective management of costly hydropower systems, providing a promising step towards resolving non-linear issues in four reservoirs (Afshar et al., 2017). Some views focused on self-adaptable parameter settings in water distribution systems, contributing to a comprehensive understanding of the algorithm's adaptability and application in addressing complex engineering and scientific challenges (Choi et al., 2017). Others introduced a multi-objective evolutionary algorithm (NSDE), for optimizing multi-purpose reservoir systems within cascade hydropower projects, balancing hydropower generation, agriculture, and ecological preservation effectively (Yazdi & Moridi, 2018). Recent findings optimized the Mosul reservoir's operation amidst uncertainty proposing a compromise solution for irrigation and power generation to minimize subjectivity (Khattab & Al-Mohseen, 2020). Enhanced the hydropower generation through optimal operation rule curves tailored to different inflow conditions using genetic algorithms and a hybrid approach, achieving a 10% improvement (Ziyad & Al-Mohseen, 2021). Conducted a comprehensive evaluation of the HSA, covering its origins, mathematical foundations, and potential applications across diverse problem areas (Dubey et al., 2021). A researchers used the nature-inspired meta-

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heuristic algorithms in optimizing dam and reservoir operations for sustainable water resource management (Chong et al., 2021). Enhanced the HSA performance for sequential hydropower reservoir optimization in river ecosystems using adaptive parameter modification and the Enhanced Harmony Search (EHS) (Niu et al., 2021). Introduced the new smart global Harmony Search algorithm (NIGHS) to enhance accuracy and convergence speed, marking a significant step in the evolution of the Harmony Search algorithm and its real-world applications (Wang et al., 2023). These studies make an important contribution to the continuous development and application of the HSA in solving complex problems related to hydropower generation and water resource management.

In this study, the HSA a technique was used to identify the optimal operating policy of two single reservoir systems in Iraq (Mosul and Bekhmah reservoirs). Mosul reservoir located on the Tigris River and the Bekhmah reservoir proposed on the Greater Zab River. The main goal of this study was to increase the annual hydropower production. To achieve this aim. The HSA was formulated using the MATLAB 2022a environment. This model was evaluated using a t-test by comparing the optimal hydropower generated with that observed during the same period of operation. The value of the t-test was 0.041, which means the performance of HAS was significant. By applying the HSA to this reservoir, operating policies were optimized, allowing for the sustainable and effective use of water resources while meeting population water demand, irrigation, and environmental requirements.

2. Definition of Methodology

2.1 Framework

HSA was built in environment of MATLAB to determine the optimal policies for two single reservoirs, which represent Mosul and Bekhmah reservoirs. The primary objective of the study is to enhance annual hydropower production from these reservoirs while ensuring compliance with all operational constraints. To achieve this goal, the study was carried out in several stages. First, Mosul reservoir was operated by adopt its observed data during ten years extend from 2010 to2019. Each scenarios include 12 months. Second, this HAS model was upgraded to be suitable for operating of Bekhmah reservoir using three modes of annual inflow scenarios (lowest, moderate, and highest rates). Finally, the annual hydropower generated from the HAS model was compared with observe data during real operating time of reservoir. Through these comprehensive stages, the optimal operational policies that maximize hydropower generation were identified with taking into account the complex operational constraints of the system, contributing to more efficient and sustainable water resource management.

2.2 Harmony Search Algorithm (HSA)

A studies proposed a creative approach to enhancing metaheuristics by introducing the HSA. Drawing inspiration from musicians' improvisation to find the perfect harmony within an ensemble or orchestra, this algorithm mimics how musicians store and vary musical combinations in their memory to compose harmonies (Geem et al., 2001). The HSA was created by the researchers to explain how a musician uses memory to choose the most attractive harmony when placing notes in a song. There is potential for tackling more optimization problems with this innovative metaheuristic approach.

2.2.1 Components of HAS

There is a set of parameters and components that represent the HSA (Lee & Geem, 2005).

1. Harmony Memory (HM): It is a memory that stores the best solutions found by the algorithm. The HM is similar to a population in other population-based optimization algorithms.

2. Harmony Memory Size (HMS): It is the number of solutions stored in the HM. The HMS is fixed during the optimization process and is an important parameter that affects the performance of the algorithm.

3. Harmony Memory Considering Rate (HMCR): It is the probability that a solution will be selected from the HM during the search process.

4. Pitch Adjusting Rate (PAR): It is the probability that a solution in the HM will be adjusted during the search process.

5. Band width (BW): It is the range of variation that is allowed for each variable in the solution when adjusting its value during the search process.

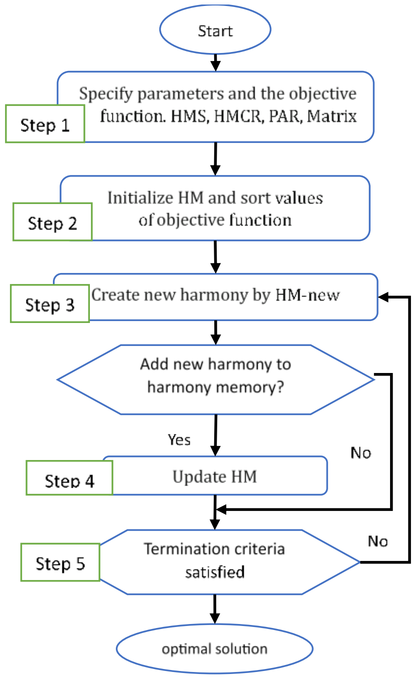

Figure 1: The general flowchart of the HSA (Bashiri-Atrabi et al., 2015)

In the context of the HSA, the typical flowchart Figure (1) of the process is described, the steps involved from initiation to completion. The initial stages involve the creation of the underlying congruity memory, specific to the region of application, and defining the boundaries for the harmony search. Crucial parameters such as the HMCR and PAR are determined. During each iteration, a key element, often an irregular number, is selected to introduce randomness into the process. If a randomly generated number is less than the HMCR, the algorithm chooses a current harmony, while if it exceeds the PAR, the pitch is altered randomly within the predefined boundaries, resulting in the generation of new harmonies. This process is iteratively repeated until either the stopping criterion is met or all elements harmonize in unison. The use of randomness and memory-based search strategies makes HSA a potent optimization technique, and its effectiveness has been demonstrated in various studies, offering promising applications in solving complex real-world problems (Karimullah et al., 2022).

2.2.2 The steps of HSA adopted in this study

The steps using in the HAS of this study are shown in Fig. **(**1) (Bashiri-Atrabi et al., 2015).

Step 1: Initialize the problem and algorithm parameters

The objective function is defined as follows:

Mean F(R) The objective function of the harmonic search algorithm used to find solutions.

subject to $R \in R_i$ $RL_i \le R_i \le RU_i$ (i = 1; 2; …NVR) (1)

R = set of the decision variables. is the set that contains all the decision variables, giving all the possible outcomes for each decision variable and representing the releases from the power house.

R_i = set of values that can be assigned to each decision variable. is a group associated with each decision variable that shows the range that can be allocated to this variable to give more detail by listing the potential outcomes of each decision variable and representing the space of the solution.

RL_i and RU_i = decision variables' minimum and maximum values.

NVR = number of design variables.

Matrix = 1000 maximum number of iterations

HMS = 60 harmony memory size

HM-new = 40 new harmony memory

PAR = 0.3 Pitch Adjusting Rate

HMCR = 0.9 Harmony Memory Consideration Rate 0< HMCR <1

BW = 0.01 Band width distance

All these parameters are referred to by the researcher (Abedinpourshotorban et al., 2016) .

Step 2: Initialize the harmony memory (HM)

The HM matrix, given by Eq. (2), is filled with randomly generated solution vectors.

$$HM = \begin{bmatrix} R^1 \\ R^2 \\ \vdots \\ R^{HMS} \end{bmatrix} \tag{2}$$

The initial HM is generated at random by Eq. (3). The range of the initial HM is [RL_i, RU_i].

$$R_i^j = RL_i + (RU_i - RL_i) * \text{rand}() \tag{3}$$

j = 1; 2; …; HMS

rand () = is a random number from a uniform distribution of [0, 1].

HMS = is there a sufficient number of solution vectors in the search memory?

Step 3: New harmony improvisation

In this step, Eq. (4) a new harmony (solution) denoted as is generated based on the following process:

$$HM_{new} = (R_{new}^1, R_{new}^2, R_{new}^3, \ldots, R_{new}^n) \tag{4}$$

The key parameter, HMCR, plays a pivotal role in the algorithm's decision-making process. It is responsible for determining whether the value of a decision variable, denoted as R_{new} Eq 5, will be selected from the harmony memory HM or generated randomly from the feasible range of R_{new}. This decision is based on a randomly generated number within the range of [0, 1]. If the random number is less than the HMCR, R_{new} is selected from the harmony memory, enabling the algorithm to exploit promising solutions that have been previously encountered. Conversely, if the random number is greater than or equal to the HMCR, R_{new} is generated randomly, facilitating exploration of the search space to discover new potential solutions. The adaptive nature of HMCR allows the HSA to strike a balance between intensification and diversification, enhancing its effectiveness in finding optimal solutions for the single storage system under consideration.

$$R_{new} \begin{cases} If \rightarrow R_{new} \in (R_{new}^1, R_{new}^2, \ldots - R_{new}^{newHMS}) & \text{Use probability HMCR} \\ else \rightarrow R_{new} \in R_i & \text{Use probability}(1 - \text{HMCR}) \end{cases} \tag{5}$$

The pitch adjustment decision is made using the PAR parameter. The process follows a probability-based approach: if a randomly generated number falls within the range [0, PAR], the variable R_{new} undergoes pitch adjustment Eq (6). On the other hand, if the random number falls within the range [PAR, 1], the variable remains unchanged without pitch adjustment. This probabilistic mechanism allows for adaptive tuning of the HSA, striking a balance between exploration and exploitation in the search process, and enhancing the algorithm's capability to efficiently find optimal solutions for the problem at hand.

$$\text{decision of pitch adjusting for } R_{new} \begin{cases} \text{Yes} & \text{with probability of PAR} \\ \text{No} & \text{with probability of } (1 - \text{PAR}) \end{cases} \tag{6}$$

$$R_{new} = R_{new} + bw * rand\ (0,1) \tag{7}$$

bw = is an arbitrary distance bandwidth.

Step 4: Revise the HM

The best value from the new optimization values created in this step is chosen over the other values created from the initial harmonics. Equation 3 is used to estimate the quality of algorithm solutions.

Step 5: Termination Standards

The HSA is stopped when it reaches the maximum number of iterations or arrays specified. If this is not the case, steps 3 and 4 should be repeated. Thus, the optimization method ends.

3. Case Study

3.1 Mosul reservoir

The Mosul reservoir taken into consideration for this study is located on the Tigris River in Iraq, roughly 50 kilometers north of Mosul city (Fig. 2). It is regarded as Iraq's biggest reservoir. The Mosul Dam is situated at 36° 37′ 49′′ North latitude and 42° 49′ 23′′ East longitude. August 1988 marked its official opening. Approximately 50,200 km2 make up the region of the reservoir in Mosul's watershed that is upstream. The Mosul reservoir serves a number of purposes, such as flood control, hydropower generation, irrigation of a significant portion of the Al-Jazera region, fisheries, and the development of the country's tourism industry. The Mosul Dam is a rockfill dam with a clay core in the center. The dam is 3650 meters long at its highest point, including a spillway that is 50 meters long, and it is 113 meters tall. The dam is 10 meters wide and 341 meters tall at its highest point. Five radial gates on the spillway allow you to regulate how much water is released. The hydroelectric station's turbines are connected to the dam by four penstocks, or tunnels. The hydroelectric plant is capable of 772 MW of power. A segment gated pair of outlets make up the bottom outlet. The reservoir's tailwater is 265 meters deep. Table 1 displays the elevations and storage volumes in the Mosul reservoir (Khattab & Al-Mohseen, 2020).

3.2 Objective Function

The HSA was developed and evaluated, starting with the Mosul dam a nd subsequently applying it to the proposed Bekhmah dam. The professional function of the system is represented Eq 8, which aims to maximize annual hydropower generation (Al-Aqeeli et al., 2016).

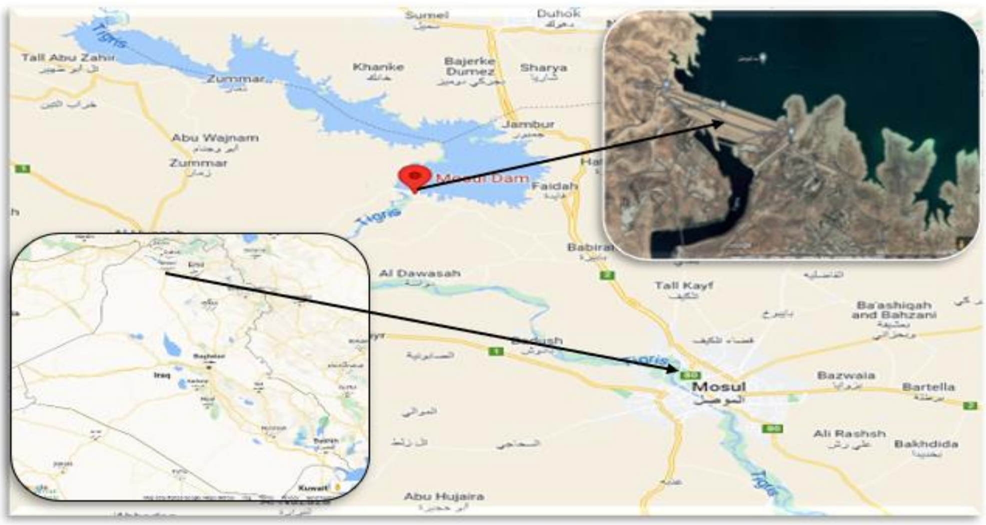

Figure 2: Location of the Mosul Dam reservoir on the Iraq map and Nineveh governorate https://www.google.com/maps

Table 1: The storage, elevations and power for the Mosul reservoirs							
Elevation of reservoirs (m.a.s.l)			**Storage of reservoirs (MCM)**			**Power of reservoirs (MW)**	
Minimum level of operational storage	Maximum level of operational storage	Maximum level of flood storage	Minimum level of operational storage	Maximum level of operational storage	Maximum level of flood storage	Minimum level of operational storage	Maximum level of operational storage
300	330	335	300	330	335	300	330

Maximize $PH_i = \sum C^* PH_i * HH_i$ for i = 1 to 12 (8)

PH_i = Power Function (MW)

PH_{i} = monthly Release from the powerhouse (MCM)

HH_i = monthly head Rate (m)

C = Constant equal to 0.003

3.3 Constraints

In order to attain the most effective solution, it is necessary to impose various constraints on this operation. These constraints carefully describe the behavior of the water storage system in a practical and real way. The reservoir's continuity equation first of constraints (Ho et al., 2015).

3.3.1 The continuity equation

The reservoir's continuity equation 9-a & 9-b is the first of these constraints. It is used to calculate the storage at the end of the month.

$SH_{i+1} = Si + I_i - RH_i + PrH_i - EvH_i$ for i = 1 to 11 (9a)

$SH_{i+1} = SH_i + I_i - RH_i + PrH_i - EvH_i$ for i = 1 to 11 (9b)

S_i = Initial storage monthly (MCM)

SH_{i+1} = monthly Storage at the end month for reservoir (MCM)

SH_i = monthly Storage at the beginning of month for reservoir (MCM)

I_i = monthly Inflow for reservoir (MCM)

RH_i = monthly Release for reservoir (MCM)

PrH_i = monthly Precipitation for reservoir (m)

EvH_i = monthly Evaporation for reservoir (m)

Was applied the equation 9-a to determine the amount of storage at the end of the month after compensation in the water balance equation in the calculated real Initial storage (Si) , which is the rate of storage for the previous month and the current month and, they are used in calculating the first month's storage from the beginning of the water year.

The used the equation 9-b to calculation the storage for the rest of the months of the aquatic year after compensation of the first month's storage in the equation of the water balance.

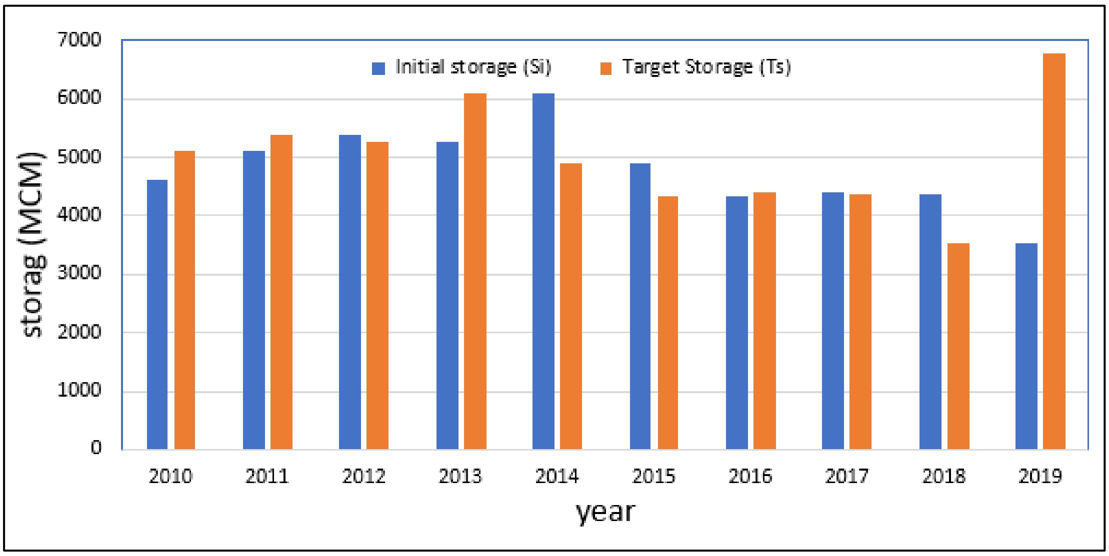

Figure 3: Initial storage &Target storage at the end Year for Mosul reservoir

In the calculations for the first month of the year, Initial storage was used in the Figure (3) to calculate storage by applying the Water balance equation 9-b.

3.3.2 The constraints of the operational storages

The storage must be greater than or equal to the maximum operational storage, as shown by Eq10.

$SH_{min} \leq SH_{i+1} \leq SH_{max}$ i= 1 to 11 (10)

SH_{min} = minimal capacity of operational storage (MCM)

SH_{max} = maximal capacity of operational storage (MCM)

3.3.3 Release to the hydropower station

The minimum value, which indicates the monthly water demand, and the maximum value, which indicates the tunnels' capacity as shown by the Eq 11.

$LR \leq RH_i \leq UR$ (11)

LR = lower limit of Release monthly water requirements (MCM)

UR = upper limit of Release represents the capacity of these tunnels (MCM)

According to Water Resources Service sources, the lower release Mosul Dam's (LR=518 MCM). includes the release amount indicated on the provision of water needs for the city, irrigation, and environmental requirement, the upper release (UR=2900 MCM) have ever passed through the gates for Mosul Dams.

3.3.4 capacity of the hydraulic reservoir

The sum of all releases must be less than or equal to the maximum amount, which indicates how much water can be stored in the hydraulic reservoir as shown the Eq 12.

$CH \geq RH_i$ (12)

CH: capacity of the hydraulic reservoir in the downstream of the river (MCM).

3.3.5 Penalty Function at end of Year

The penalty function is an important limitation in calculating the main objective function of maximizing hydropower generation. The storage at the end of the last month of the water year is intended to be equal to the target storage or higher, as described in the Eq 13. (Al-Aqeeli et al., 2016).

$$SH_e12 \geq Ts \tag{13}$$

SH_e12 = storage at the end of the last month (MCM).

Ts= target storage at the end of the last month (MCM).

These constraints, the penalty function for storage calculations is calculated when the amount of storage at the end of the year is less than the target storage, as it is adjusted by applying the storage constraints are represented for Eq (14):

$$PnH \text{ for } (SH_{ie}12, Ts) = K^*[SH_e12 - Ts]^2 \tag{14}$$

for $SH_e12 < Ts$

PnH**=** penalty of min storage and target ending storage for HSA.

K = 10 Constant

From one of the real operating factories used in this HSA, the storage account at the end of the year target storage (TS) is mention for equation (13) should not be less than the real storage and the values are indicated in the Figure (3)

Note: The units used in Eq (10,11,12,13,14) are usually (MCM) millions of cubic meters.

The unit used (m.a.s.l.) stands for meters above sea level.

3.4 Evaluating the Optimization Model

An improvement the HSA model was built for one reservoir which was subsequently employed to operate the conductor reservoirs in real-time while adhering to all operational constraints of the system. The real-time operation extended over 10 water years, totaling 120 months. The HS algorithm was executed ten times for the conductor reservoirs, with each run spanning 12 months. To accurately simulate the reservoir actual operation each year, the HSA model's initial and final storage levels were set accordingly. The initial storage was equivalent to the observed storage for each run, while the final target storage was set to be equal to or greater than the initial storage for the next year (Al-Aqeeli & Mahmood Agha, 2020).

3.5 t-test evaluation

A statistical t-test is employed to compare the means of two separate samples. This test finds applications in several fields, including the social sciences, medicine, and engineering. There are multiple steps in the process: First, get the null (H0) and alternative (H1) hypotheses ready. Second, determine the t-weighted value using the relevant t-test equation. Third, figure out the probability (p-value) that corresponds to the t-weighted value. Fourth, comparing the p-value with a pre-defined level of statistical import is often set at 0.05. Either acceptance or rejection of the null hypothesis depends on the comparison and the size of the difference between the two values. Researchers can determine the significance of the observed differences between the means of the two samples by using this method to draw conclusions (Kim, 2019).

The HSA was tested and evaluated by applying the t-test statistical test to compare with the optimal hydropower obtained with the Observed hydropower and the t-test calculation, which used SPSS softwareand showing that the test value is 0.041 less than 0.05, the results indicated to accept the substitute hypothesis and the benefit of using the HSA to create a new operational strategy for the Mosul reservoir.

4. Application of Has

4.1 Bekhmah Dam Reservoir

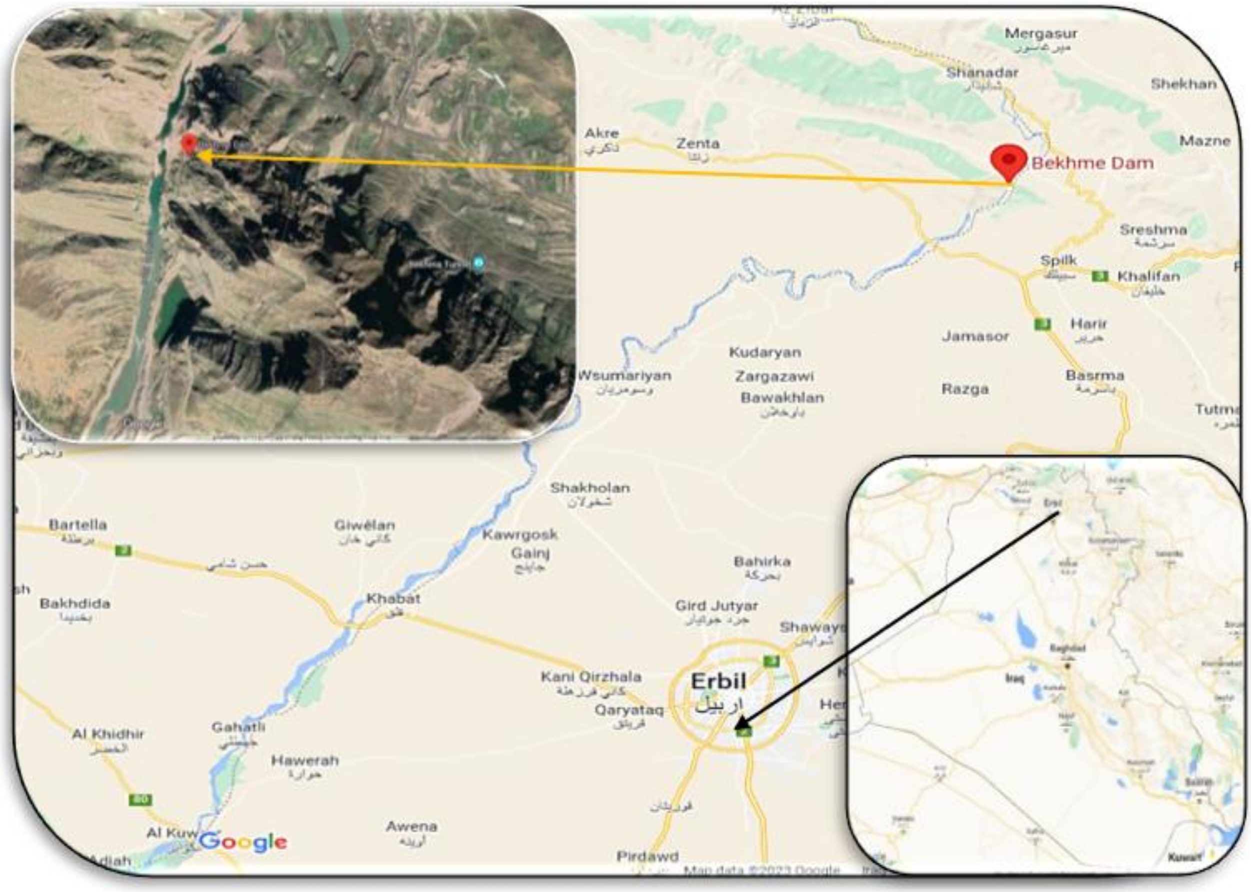

Figure 4: Location of the Bekhmah dam reservoir on the Iraq map and Erbil governorate https://www.google.com/maps

The Greater Zab River basin, a major tributary of the Tigris River, originating in the south-eastern Turkish mountains at an elevation of 4,168 meters above sea level. Flowing into Iraq north of the Erbil between latitudes 36° and 38°N and longitudes 43°18' and 44°18'E, the river spans 407 km in length (290 km in Iraq) and covers a total area of 2630 km2 Figure (4), primarily located in Turkey with a small portion in Iran. The northern region of Iraq houses the most significant part of the river basin, encompassing approximately 50,330 km2, including the capital city of Erbil. It is a vital water resource shared by Iraq and Turkey, receiving an average annual flow of 383 m3/sec. The upper part of the catchment receives up to 1700 mm/year of rainfall, while the lower part receives only 300 mm/year. The GZRB's water resources are regulated by the unfinished Bekhmah Dam, situated around 100 km from Erbil city and serving primarily for irrigation and hydroelectricity. With a 17.1 km3 reservoir and storage capacity, the Bekhmah Dam will control the flow of the Greater Zab, contributing to an additional 565,000 ha of irrigable land. The maximum spillway release by flood routing is limited to 8000 m3/sec, and the hydroelectric facility can release up to 1000 m3/sec of flow, catering to downstream irrigation and urban water needs. The ideal power station scale has a maximum output of 1500 MW, with the maximum flood water retention level being 599 m, the average high water level being 578 m, and the effective reservoir capacity being 12600 m3 (Karpuzcu, 2018).

4.2 Constraints Bekhmah reservoir

After the case was studied and its effectiveness verified on the Mosul dam reservoir, three models of flow (minimum, average and maximum) for annual discharge measured during the same time period from (2010 to 2019) were applied to the proposed Bekhmah dam on the Greater Zab River, The Mosul dam was Constraints to the same factors, some of which will be discussed.

Table 2: The storage, elevations and power for the Bekhmah reservoirs

Elevation of reservoirs (m.a.s.l)			**Storage of reservoirs** (MCM)			**Power of reservoirs** (MW)	
Minimum level of operational storage	Maximum level of operational storage	Maximum level of flood storage	Minimum operational storage of reservoir	Maximum operational storage of reservoir	Maximum flood storage of reservoir	Maximum power operational reservoir	No. of turbines
455	578	599	4470	13670	17100	1500	6

4.2.1 *The continuity equation*

When the storage accounts using the water balance equation (9a), the initial storage of the operating storage rate specified in modification Eq (15) was used as both the minimum operating storage and the maximum operating storage in table (2).

$$S_i = ((S_{\min} + S_{max})/2) \quad (15)$$

Initial monthly storage

4.2.2 *Release to the hydropower station*

The minimum demand for water requirements population and agricultural requirements, Tigris River Req Flow and environmental requirements are implicitly provided through these needs, is approved and referred to in the Figure (5) and the maximum discharge is the amount of upper limit of Release for the Greater Zab River is 2590 MCM All measurements were taken at Infraz station.

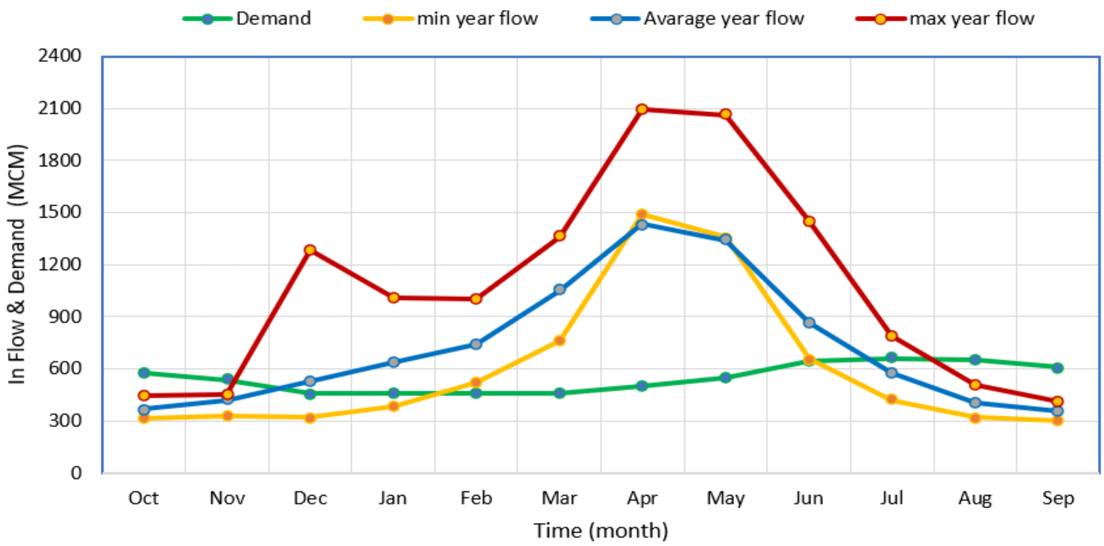

Figure 5: In Flow & Demand VS Time for Infraz Station

4.2.3 *The End Storage at the end of Year*

The equation's Eq (16) end-year storage calculation for target storage (TS) from one of the actual operating used in this HSA not be less than (values in the equation consisting of the minimum operating storage added to the population requirements with irrigation for three months at the end of the water year), So we can provide water requirements at the beginning of next year**.**

$$Ts = (S_{\min}+70) \quad (16)$$

Target ending storage.

This Number (70 MCM) in Eq (16) is represents the total water requirements for the last three months of the water year, consisting of the (water needs of the population as well as irrigation and environmental requirements became implied in the study area), to ensure water availability at the beginning of the next water year.

5. Results and Discussion

5.1 Mosul reservoir

The code for the HAS was built on a single storage system represented by the Mosul reservoir. It was operated over 10 scenarios (years) from 2010 to 2019 to create the optimal operating policy to maximize hydropower generation as indicated in the Table 3.

5.1.1 *Evaluating the Optimization Mosul Reservoir Model*

The optimal hydropower generation values were compared with the observed results using a t-test to support the validity of these findings. A t-test statistic of 0.041 was computed as a result, indicating statistical significance.

Tabel 3: Compare the Observed Power and Optimal Power of The Mosul Reservoir

Pop=1000	GAN= 1000	Iteration= 1000	
Year	Observed power	optimal power	T test
2010	2348	3394	0.041
2011	2018	2756	
2012	2161	2680	
2013	2797	3486	
2014	1114	1694	
2015	2185	2683	
2016	2208	2988	
2017	1573	2498	
2018	752	1489	
2019	3149	4395	

5.1.2 Results of Optimization Mosul Reservoir Model

Results will be presented for three scenarios: drought years (minimum, average and maximum annual discharge), for the selected 10 years. Three scenarios will be shown this result highlights the HAS model's efficacy in maximizing reservoir operation and points to its potential as a useful reservoir management tool.

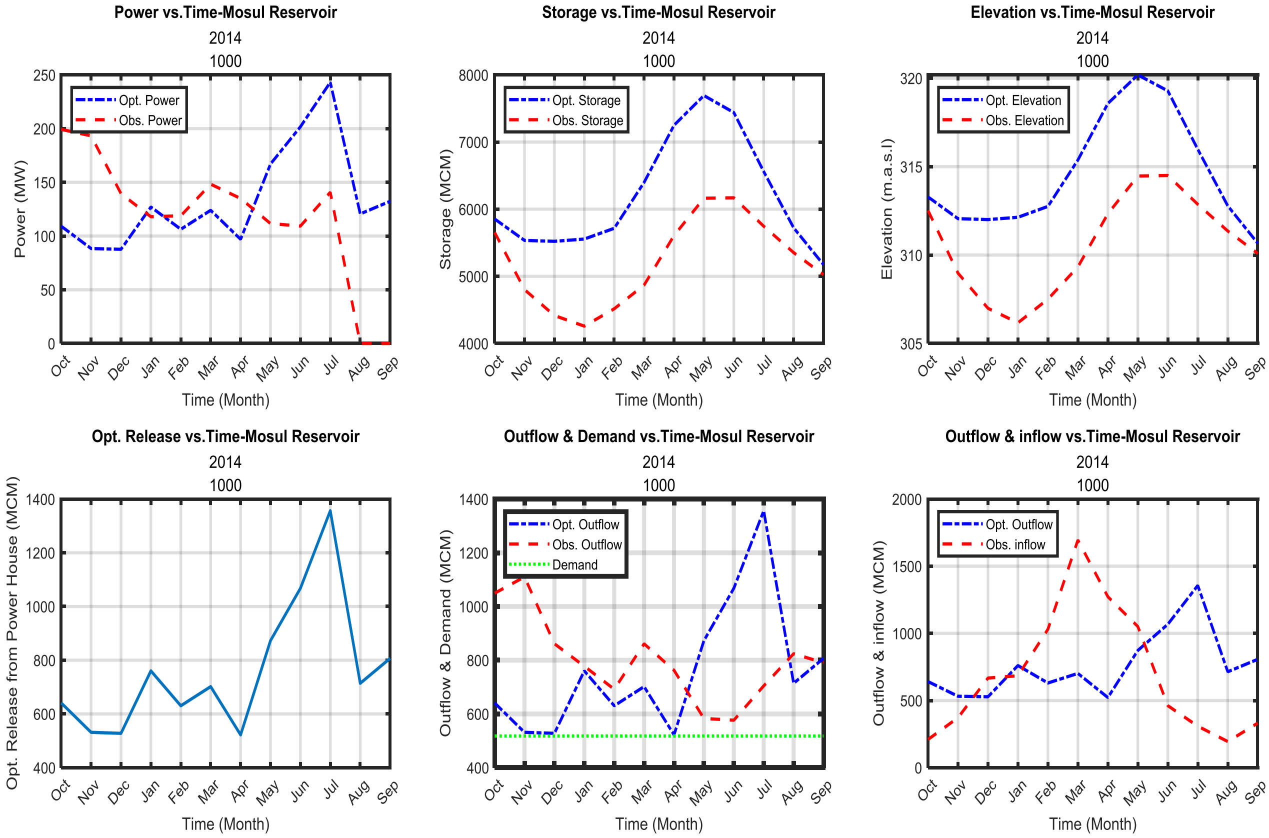

Figure 6: Scenario 2013 - 2014: Minimum annual discharge to Mosul reservoir during study period.

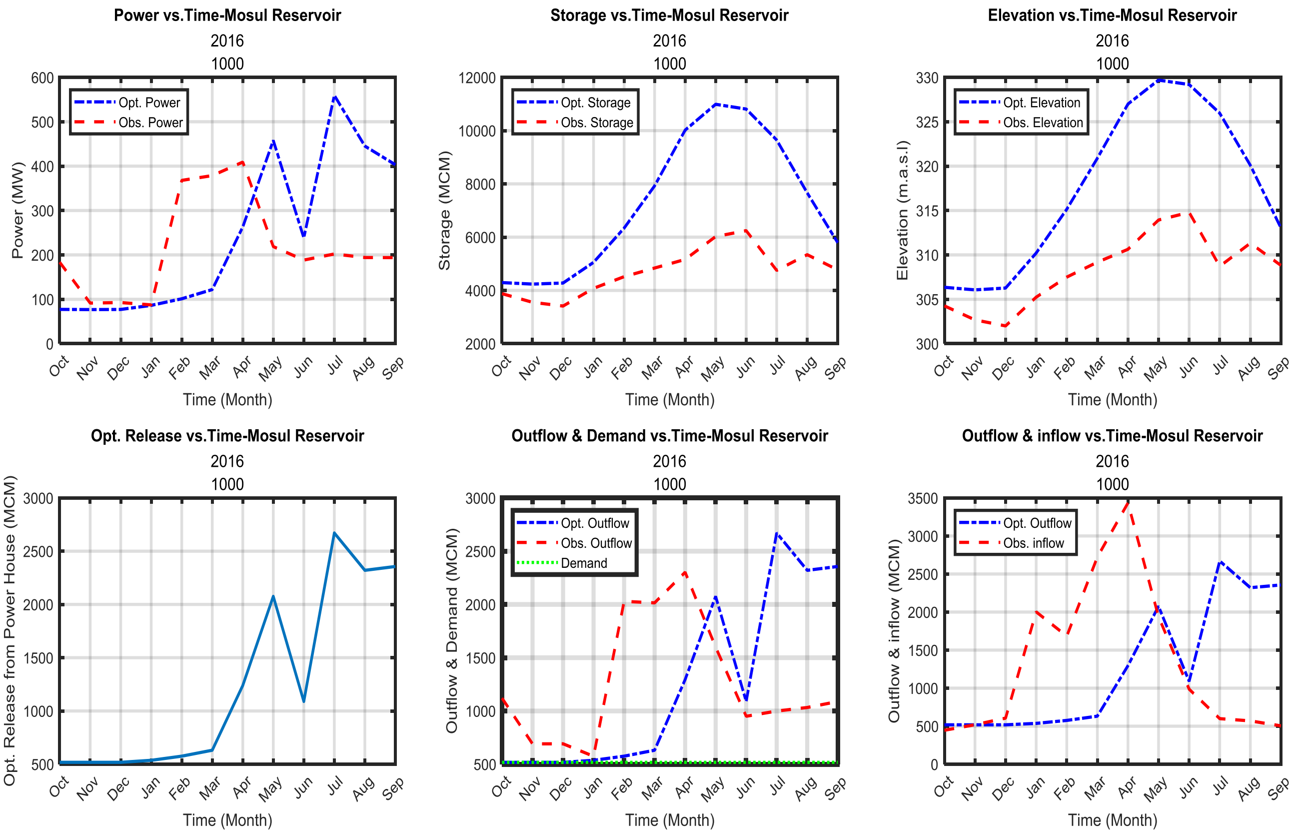

Figure 7: Scenario 2015- 2016 Average annual discharge to the Mosul reservoir during the study period.

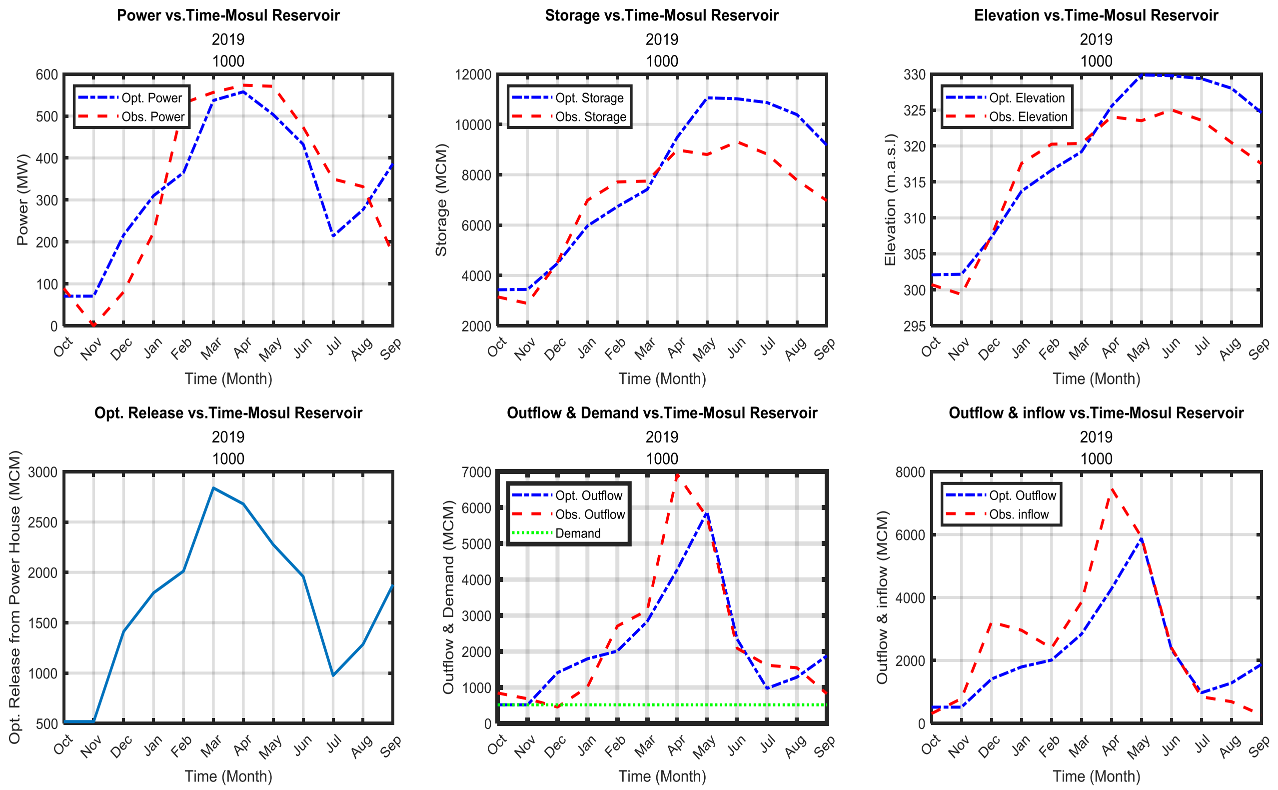

Figure 8: Scenario 2018-2019 Maximum annual discharge to the Mosul reservoir during the study period.

5.2 Bekhmah reservoir

After monitoring and confirming its effectiveness on the Mosul reservoir, it was applied to the proposed Bekhmah dam on the Greater Zab River.

Results for three flow models (minimum, medium, and maximum) for measured annual discharge were obtained from 2010 to 2019. and obtain a new operating policy that can be implemented if the dam is built and realistically.

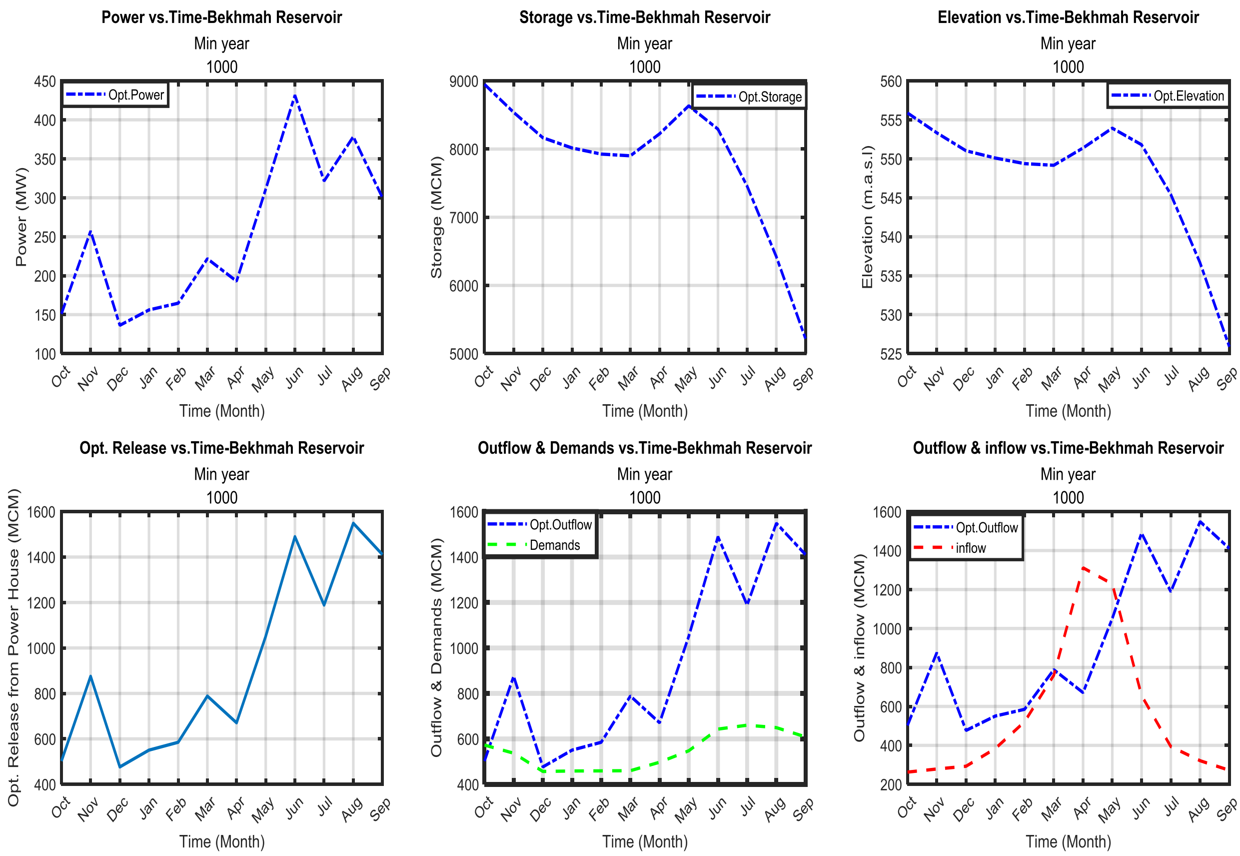

Figure 9: The results represent the Minimum annual discharge of the Bekhmah reservoir

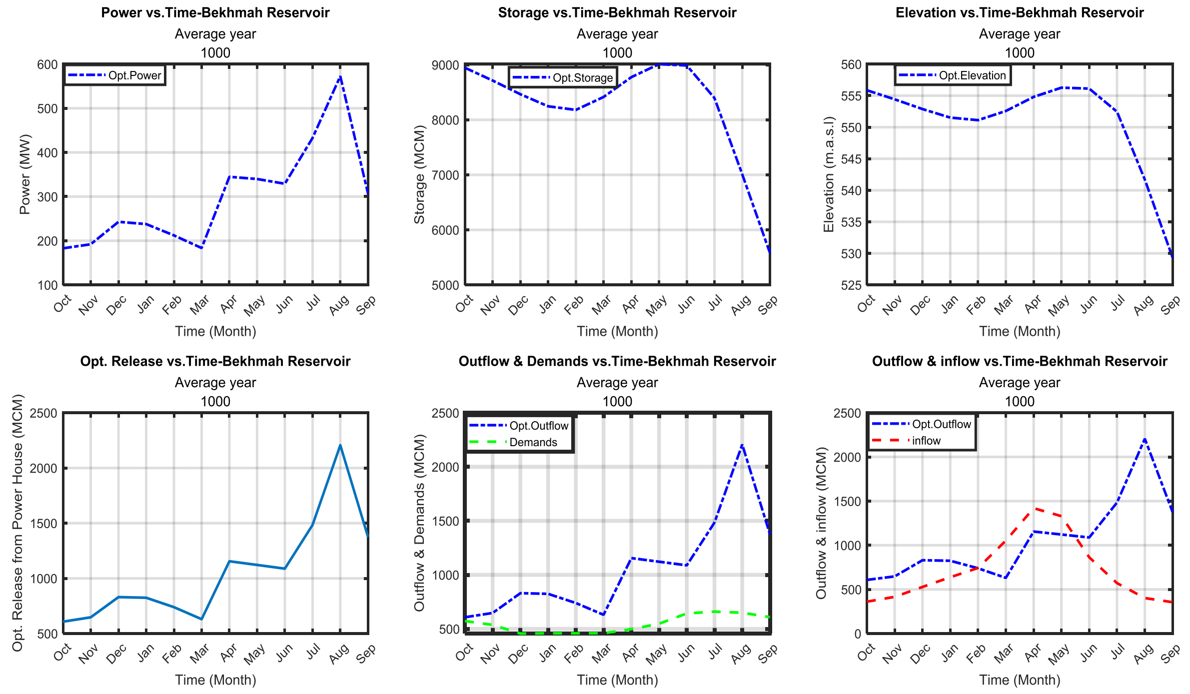

Figure 10: The results represent the Average annual discharge of the Bekhmah reservoir.

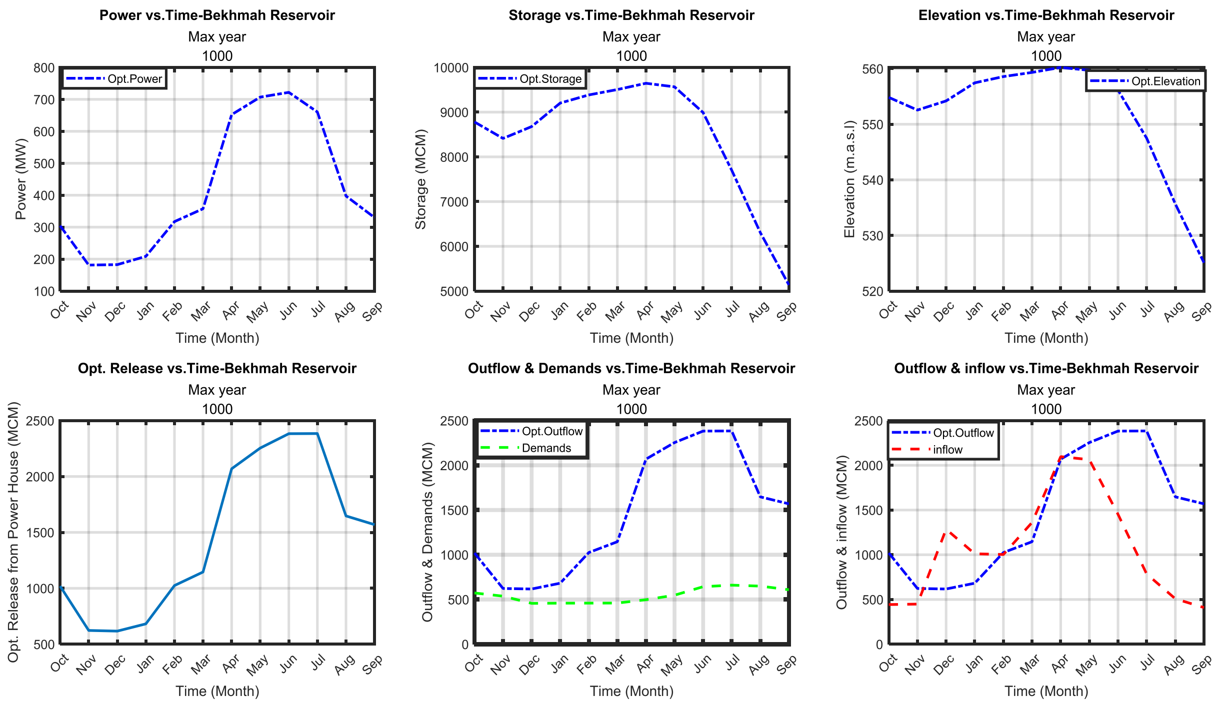

Figure 11: The results represent the Maximum annual discharge of the Bekhmah reservoir.

6. Conclusions

This research used the HSA as a powerful metaheuristic optimization tool to create optimal operating policies for two single reservoir systems in Iraq: the Mosul reservoir and the proposed Bekhmah reservoir. The primary objective was to maximize the annual hydropower generation while respecting various operational constraints. The annual hydropower generation using the HAS model of Mosul reservoir was better than real operation through the ten scenarios used. To confirm the ability of this results, the t-test was calculated by comparison the optimal hydropower generation with the observed. From this comparison, the t-test statistical was 0.041, which mains that HAS is significant. This result indicated to the effectiveness of HAS model in optimize the reservoir operating. The HAS model was developed and applied in the operating of Bekhmah reservoir to specify the optimal policy under three scenarios of annual inflow (minimum, average, and maximum). These operation policies of this reservoir aimed to address water storage requirements for the water needs of the population, irrigation to ensure the availability of water during first three months of the following year. The results produce from the HSA model of Bekhmah reservoir were promised to apply this model in the operating of any water storage system by considering the hydrological aspects of that system.

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