

Impact of New Dams Built on Upstream Of Lesser Zab River on Dokan Dam Using HEC-Ressim Model

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ABSTRACT

Recent years have witnessed significant declines in surface water quantities due to factors such as population density, climate change, and water pollution. Iraq is one of the countries that has suffered from water scarcity, particularly as a result of the upstream countries' water usage policies concerning the Tigris and Euphrates rivers. Therefore, given that most studies have focused on the operational policies of dams and hydraulic structures, there is a growing need to study and analyze the impact of upstream dam construction on the operation of Iraqi dams, such as Dokan Dam, located on the Lesser Zab River. It is one of the most important dams to study due to its size and direct impact on the surrounding areas. The aim is to understand the changes in the performance of these structures and the impact of declining water levels. To achieve this objective, after collecting sufficient data, the HEC-ResSim program—a water resources simulation tool—was used. This program has a powerful capability to simulate reservoir systems, supporting practical decision-making for their operation to meet various requirements such as flood control, power generation, irrigation, water supply, and environmental protection through different operating policies. The study used this program to assess the impact on the dam's operation over a 30-year period, from 1980 to 2010. The results showed that HEC-ResSim was effective in simulating the system's operation and in studying daily and monthly discharges, demonstrating its flexibility in handling various storage systems.

Keywords: Dokan Dam; Impact; HEC-Ressim; Simulation; Lesser Zab.

1. Introduction

Water covers about 71% of the Earth's surface [1], the 97% of this being saltwater and the remaining 3% being freshwater. A little more than two-thirds of this freshwater is frozen in polar ice caps and glaciers. The freshwater that is not frozen is primarily found as surface water and groundwater. As a result, water resources are under threat due to conflict, scarcity, and pollution.

Global groundwater supplies are declining at an increasing rate, with depletion becoming more prominent. The availability of water is an important consideration at all times. Some people use water intermittently, such as farmers who need large amounts of water in the spring but do not require any in the winter. In such situations, surface water must be stored for the entire year and released over a short period.

On the other hand, some users need water continuously, such as power plants that use water for cooling. In this case, the surface water system requires sufficient storage capacity to meet demand when the water flow is less than the power plant's needs. However, the maximum consumption of surface water is limited to the rainfall rate in that catchment area [2, 3].

The Tigris, Euphrates, and their tributaries account for all of the surface water in Iraq. The surface runoff of the Tigris River is projected to range from 41.2 to 58.3 billion cubic meters annually, while the surface runoff of the Euphrates River is expected to range from 27 billion to 35.1 billion cubic meters annually. However, the fact that the sources of these major rivers are located outside of Iraq has long been a source of concern, placing Iraq in a difficult position when planning to manage and control these water resources. It is generally accepted that the amount of surface flow has decreased by 30% due to the depletion of the resource. Furthermore, it is expected that the percentage of direct water available to Iraq will decrease by 60% over the next 20 years [4].

In addition to the main rivers, there are several important tributaries, including the Little Zab River, which originates in Iran and joins the Tigris River near the town of Zab, close to Kirkuk. It serves as a vital lifeline for the region, as approximately 100,000 people primarily rely on its water. In the past, frequent and severe floods of the Little Zab River were common in northeastern Iraq. The river's flow rate through the Dokan Gorge reached about 26 cubic meters per minute during the dry season and more than 3,000 cubic meters per minute during flooding. To control these floods and ensure water availability, the decision was made in 1954 to construct the Dokan Dam—an arch dam on the Little Zab River in the Dokan Gorge, located 60 kilometers northwest of the city of Sulaymaniyah.

At the headwaters of Dokan Lake, a concrete arch dam was constructed for multiple purposes. The dam has a maximum height of 116 meters. It features a reservoir with a length of 360 km and a maximum storage capacity of 6.97 km³. The dam serves to generate hydroelectric power, regulate river water levels, and store water for irrigation. The Little Zab drainage basin extends over 22,250 square kilometers from the site of the Dokan Dam. This study utilizes historical data, dam specifications, and water requirements within the specific dam management program (HEC-ResSim) to determine the optimal monthly operating rules for the Dokan reservoir under the worst-case scenario.

HEC-ResSim is one of the most important software packages used worldwide for simulating water resource systems. Due to its extensive and advanced capabilities, it has been utilized in numerous research studies globally. Below is a brief overview of some of these studies.

A study conducted by Madushanka 2023 [5], investigated and evaluated the present and future water availability of the Kalu Ganga Reservoir. The study utilized historical weather data, while future water availability was estimated using projected data derived from downscaled climate change models. The SWAT and HEC-ResSim models, along with climate change forecast data, have proven to be valuable tools for identifying water availability challenges driven by climate change.

Abdulateef 2021 [6], presented a study applying the HEC-ResSim model to simulate the operation of the Mosul and Dokan Reservoirs, as well as the Samarra Barrage, during the dry period of 1999-2000, using historical data. The simulation plots for the Mosul Reservoir show that the storage pool elevation remained within the conservation zone, demonstrating its ability to release the minimum downstream flow requirements. In contrast, the operating pool level of the Dokan Reservoir was shown to be below the conservation level.

Abdulateef 2022 [7], used the HEC-ResSim application to simulate and evaluate the behavior of the reservoir system, represented by the Mosul and Dokan Reservoirs, as well as the Samarra Barrage, during the 1987-1988 flood period. The simulation plots revealed the ability of the existing infrastructure to mitigate flood risks during such events.

Sulaima (2021) [8], used the HEC-ResSim model to simulate the Dokan Dam, studying the operational behavior of the reservoir and assessing the model's capability in representing and simulating the real system. The study was based on monthly discharge data from 1986 to 2016, measured at the inlet of the Dokan Dam reservoir. The results showed that HEC-ResSim 3.0 performed well in simulating monthly discharges. Therefore, it could be used for improved water system analysis in this study area.

McKinney (2011) [9], simulated the reservoir system in the Romanian Arges River Basin using HEC-ResSim 2.0. The basin contains eight reservoirs and seven significant tributaries. The study aimed to enhance system understanding and identify optimal flood control strategies that could be integrated with hydropower production.

2. Study area

The Lesser Zab is the third-largest international transboundary tributary shared by Iran and Iraq, merging with the Tigris River within Iraqi territory. It has a length of approximately 456 km, originating from western Iran in the Zagros Mountains, where elevations exceed 3,200 meters above sea level. The basin is highly mountainous, as illustrated in Figures 1, 2, and 3. The river has an average discharge of 77 m³/sec as it flows into Iraq, where it joins the Tigris River. The Lesser Zab River has a catchment area of 22,250 km², with 24% located in Iran and 76% in Iraq. It contributes approximately 13.74% (6.868 BCM/year) of the Tigris River's annual flow Varoujan, 2013 [10].

In 1959, the construction of the Dokan Dam, an arch concrete dam on the Lesser Zab River, was completed approximately 65 kilometers northwest of Sulaymaniyah. The dam has a storage capacity of 6.8 billion cubic meters of water and features two spillways: a shift spillway and a box spillway, along with two bottom outlets for irrigation. The primary purposes of the Dokan Dam include flood control, irrigation, and hydroelectric power

production. It supplies water to the Klesa, Kirkuk, and Heweja irrigation projects. In 1982, the dam was further developed into a hydroelectric power plant.

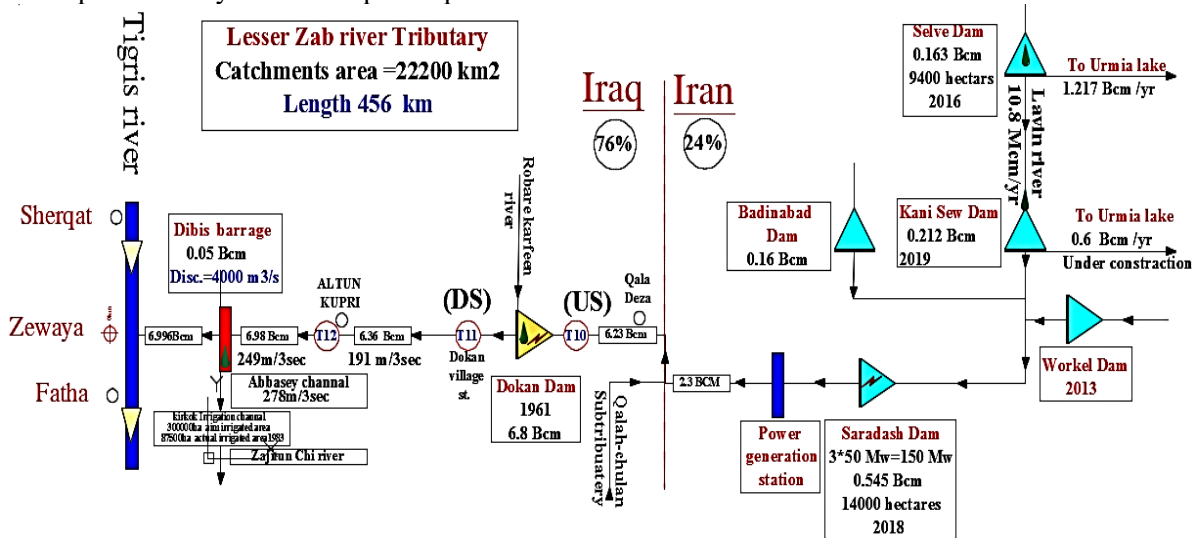


Figure 1. Schematic Diagram of The Lesser Zab Basin, Showing Iranian And Iraqi Dams And The Average Flow Rate.

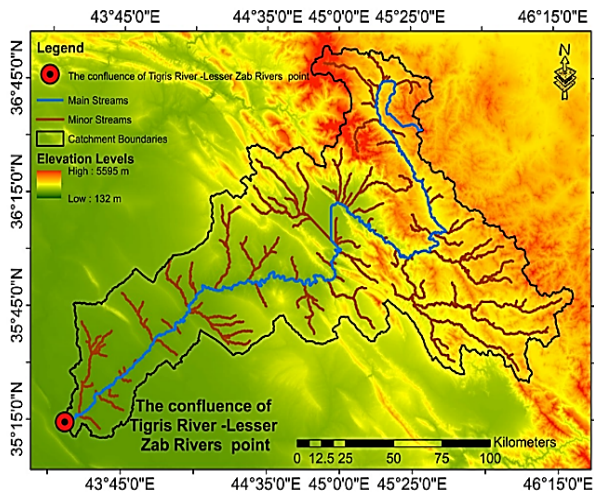


Figure 2. The Watershed of Lesser Zab By Gis

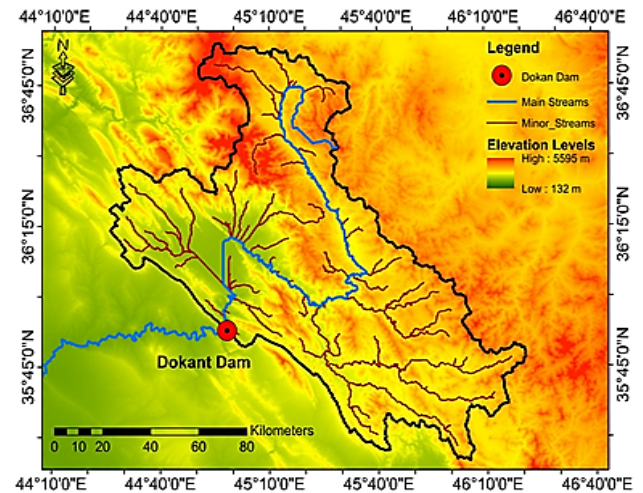


Figure 3. The Watershed of Dokan Dam By Gis

3. Methodology

The methodology followed in this research can be summarized by the following steps.

3.1. Data used

Data was collected from various documents over a 30-year period (1980–2010). This data was analyzed to fill gaps and compile a comprehensive database of all available information. Additionally, the physical and hydrological characteristics of the system were used to develop a simulation model.

For further details, climatological data—including rainfall, evaporation, maximum and minimum temperatures, relative humidity, wind speed, and sunshine duration—was obtained from the Ministry of Irrigation for the period 1980–2010. The model's input of average areal precipitation for each catchment was calculated using the Thiessen method. The number of rainfall stations used for each catchment was also considered.

Daily Class A pan evaporation data from the Kirkuk climate station was used to estimate evapotranspiration using the modified Blaney-Criddle method. Additionally, daily streamflow data was obtained from the Ministry of Irrigation in Iraq.

Data management involves several key steps, which can be summarized as follows:

1. Collecting data from various documents and water resource authorities in Iraq.
2. Screening the data, filling gaps, and estimating overlap for each catchment in the study basin.

3. Creating a comprehensive database of all available data to facilitate further analysis and processing.
4. Splitting the data into specific trial periods, resulting in three sections of overlapping accessible data.

These data categories include meteorological, hydrological, and irrigation data, as well as information on population, water requirements, projects, critical reports, theses, and previous research related to the study area. Data sources include the Iraqi Ministry of Water Resources, the Ministry of Irrigation, and meteorological stations.

Table. 1 Monthly Mean of Precipitation And Evaporation With Total Monthly Water Requirements Within Lesser Zab River Till Tigris Basin Conflicts.

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precipitation (mm /month)	17	77	124	124	108	116	96	27	1.1	0.3	0.06	0.8
Evaporation(mm/month)	132	65	10	20	40	56	85	175	232	280	268	204
Water requirements Lesser zab from Dokan dam to Tigris conflict (Mm ³)	348	257	109	106	206	290	412	392	453	463	270	282

3.2. Stream Flow Analysis.

The flow rate is summarized in Figures 4 and 5, which illustrate the general decreasing trend in average flow for the period (1955–2015).

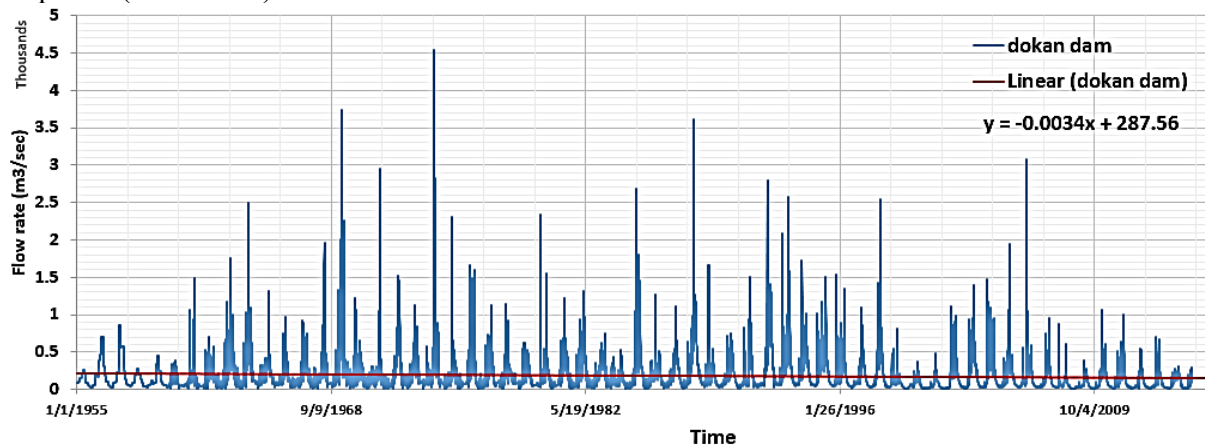


Figure 4. Daily Mean Discharge of Lesser Zab River At Dokan Dam Station, 1955–2014.

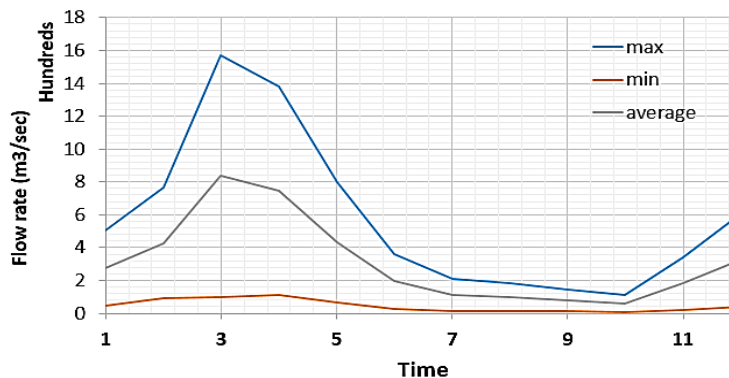


Figure 5. Average Daily Discharge Per Month For Lesser Zab River At Dokan, Years 1952–2014.

3.3. Elevation, Area, and Storage Characteristic curves.

Several relationships between elevation, surface area, and storage were derived for the Dokan Reservoir system. These relationships enable the estimation of surface area or water level based on the given storage in the reservoir, and vice versa. Figures 6 and 7 illustrate the relationships between surface area, storage volume, and elevation. Based on these curves, mathematical equations were developed to estimate surface area and storage volume for use in the model.

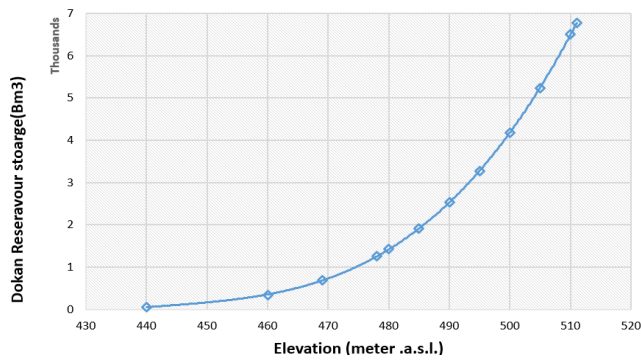


Figure 6. Characteristic Curve For Elevation-Area For Dokan Reservoir On Lesser Zab River

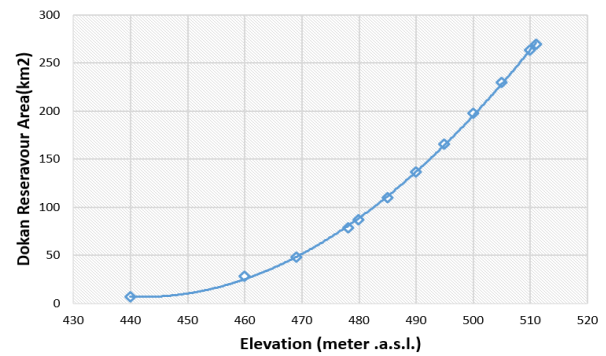


Figure 7. Characteristic Curve For Elevation Storage For Dokan Reservoir On Lesser Zab River

$$Area = [-5.94 \times 10^5 \times El^3] + [1.3921 \times 10^{-1} \times El^2] - [8.8305 \times El] - 1.7349 \times 10^4 \quad (1)$$

$$Storage = [1.97 \times 10^2 \times El^3] - [(2.63 \times 10 \times El^2] + [1.1697 \times El] - 1.7349 \times 10^6 \quad (2)$$

Where:

EL : the Dokan dam water reservoir elevation.

3.4. Model (HEC-RESSIM) used

HEC-ResSim (Hydrologic Engineering Center – Reservoir System Simulation) is a water resources simulation program developed by the U.S. Army Corps of Engineers (USACE) in 2003 as a replacement for HEC-5. The latest version, HEC-ResSim 3.0, was released in April 2007. This program has powerful capabilities for simulating reservoir systems, supporting practical decision-making for operations such as flood control, power generation, irrigation, water supply, and environmental protection through various operating policies.

The program consists of three main phases (modules), each requiring specific system data inputs and providing distinct tools and commands. These phases are as follows (HEC, 2007):

1. Watershed setup module

In this phase, the watershed is defined and planned, and the system framework is established using a digital map to draw and identify the river channel and its tributaries. Existing and planned projects are then identified, which may include dams, irrigation projects, diversions, levees, impact areas, and hydraulic and hydrological data monitoring sites.

2. Reservoir network definition module

This phase defines the physical and operational properties of the reservoirs, including:

- Elevation-area-storage curves
- Dam specifications (e.g., release gates)
- Storage zones and operational rules
- Hydroelectric plant specifications
- River characteristics

Additionally, different scenarios are developed by inputting data series into the program. Each scenario can contain multiple alternatives, depending on input data and the selected operating plan.

3. Simulation module

In this phase, different scenarios are simulated to obtain and analyze results, which can be displayed as graphs or tables. The program allows for the simultaneous comparison of multiple alternatives. Additionally, it offers various time intervals for the simulation period, ranging from 15 minutes to one day.

The methodology followed in this research is summarized using flowcharts, as shown in Figure 8.

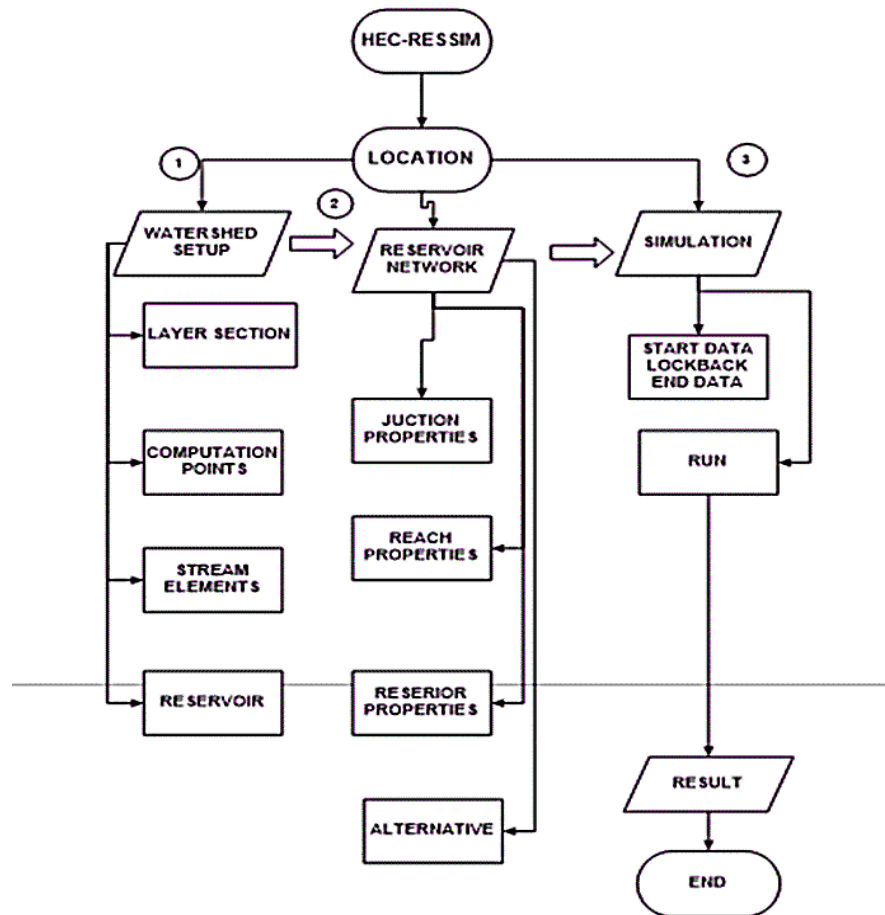


Figure 8. Flow Chart for Dokan Dam Simulation

3.5. Scenario suggested used

The worst-case scenario was applied to the operation of Dokan Dam to evaluate its capacity to meet water demands following shortages caused by the construction of Iranian dams at the river's headwaters. This scenario considered the dam's use for the (Household water requirements, Environmental needs, 100% irrigation, Fish farms, Forests, Industry).

The results of this assessment are outlined below.

4. Results

The required scenario was simulated to generate outputs and analyses, which were displayed in the form of graphs or tables. The program also offers multiple time interval options for the simulation period, ranging from 15 minutes to one day (HEC-ResSim 3.0).

The results were based on the assumption that the water stored in Dokan Dam would support Sulaymaniyah Governorate, Kirkuk City, and surrounding agricultural projects. The Dokan Dam reservoir simulation model was executed for the worst-case scenario over a period from 1980 to 2010. This scenario considered water usage according to priority.

4.1. Impacts on Reservoir water storage

Figure 9 illustrates the annual water storage in the Lesser Zab River following the construction of Iranian dams, without considering downstream water requirements. The storage levels have dropped to as low as 69.6 million cubic meters at times, with an average storage of approximately 1.82 billion cubic meters. This represents only 28.48% of the Dokan Dam's total storage capacity of 6.7 billion cubic meters.

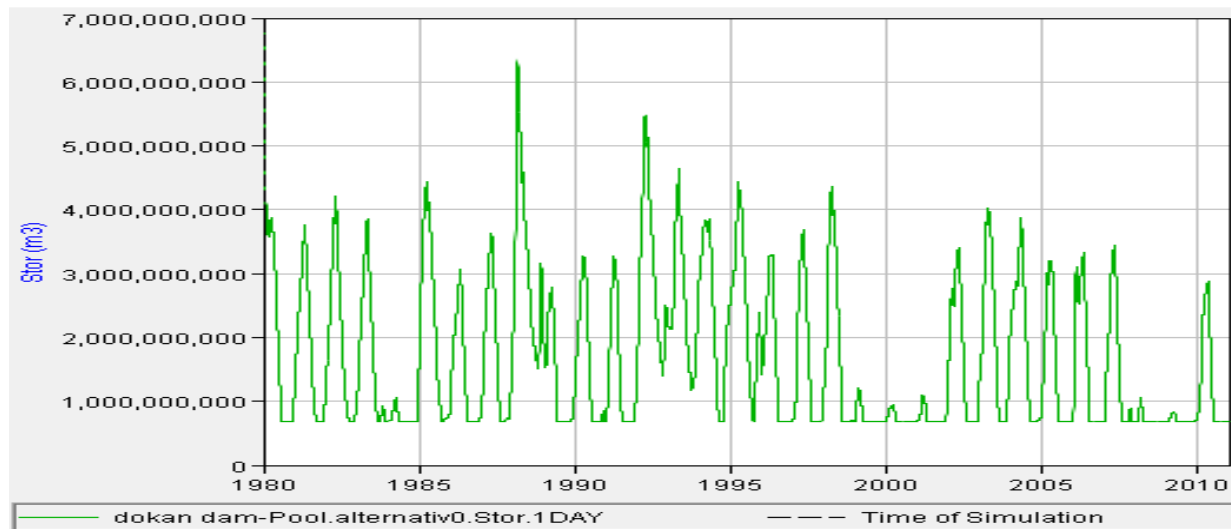


Figure 9. The Storage Level After Iranian Dams Construction By HEC-Ressim

4.2. Impacts on Reservoir Water Elevation

Figure 10 illustrates the water level fluctuations in the reservoir. Notably, the lowest recorded water level during the simulation period was 469 meters, which is below the minimum operating level of 479 meters. Furthermore, this decline has intensified in recent years.

Based on the current findings and considering the ongoing construction of Iranian dams, it is anticipated that water levels will continue to decrease in the coming years. As a result, the dam may become incapable of meeting the water demands for which it was originally designed.

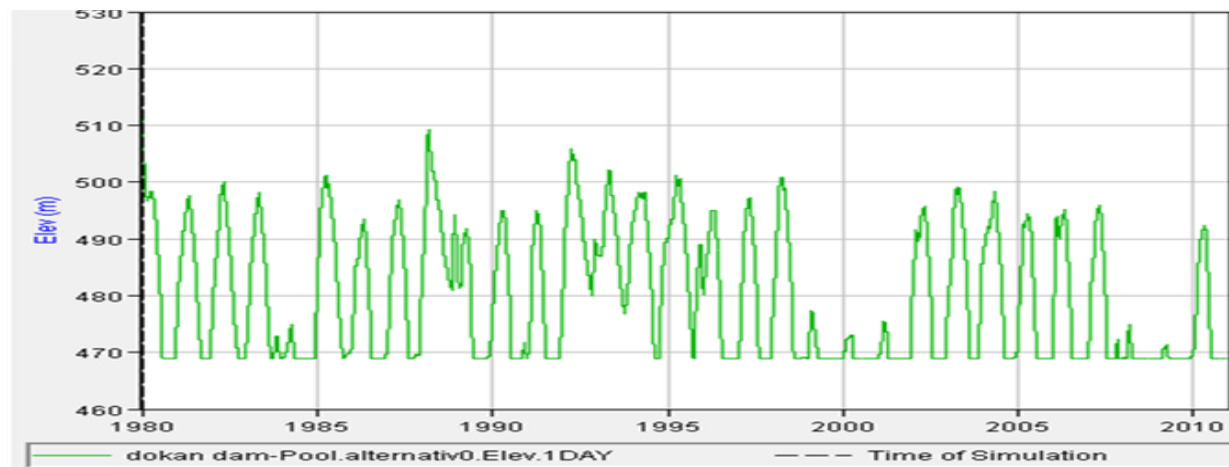


Figure 10. The Water Elevation Level After Iranian Dam's Construction by HEC-Ressim.

4.3. Impacts on Electrical power generation

Hydropower generation is one of the primary multi-purpose objectives of the Dokan Dam. As previously discussed, the water depth above the dead storage level in the reservoir has been affected by the construction of the Iranian dam, directly impacting hydropower production.

Based on the calculated results, the hydropower generation rate has not exceeded 13%, with a maximum recorded output of 354 megawatts falling short of the plant's required capacity of 400 megawatts. Furthermore, whenever the water level drops below the operational threshold, the power plant ceases production entirely.

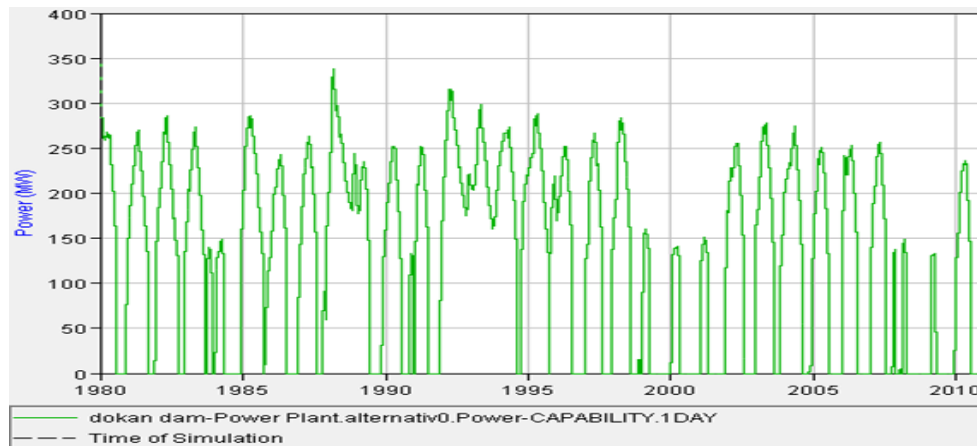


Figure 11. Electric Power Generation After Iranian Dam Construction By HEC-Ressim

By comparing the model-generated values with the recorded release values using the correlation coefficient, which reached 0.72 (as shown in Figure 11), the actual operation of reservoir releases was tested. The comparison demonstrated a close alignment between the simulated model outputs and the observed reservoir release data.

Additionally, the operating behaviour of the dam reservoir was evaluated by analysing the changes in inflow and outflow and their impact on the reservoir volume. A consistent relationship was observed between these variables during both increase and decrease periods. The correlation coefficient between the reservoir inflow and outflow was calculated, reaching 0.89 (as shown in Figure 12), further validating the model's reliability.

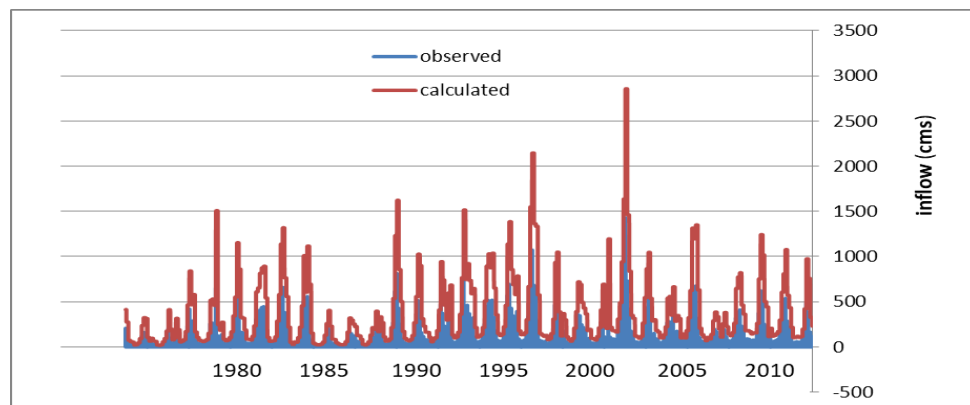


Figure 12. The Measured and Calculated Release Values from The Dokan Reservoir

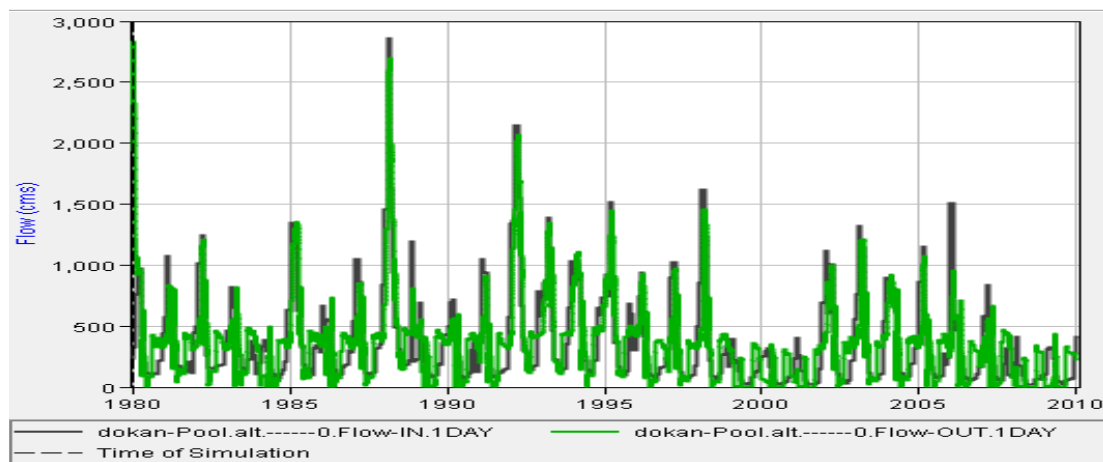


Figure 13. Inflow and Outflow During Simulation From Dokan Dam By HEC-Ressim

Table 2. Results Obtained From The Simulation Model of The Dokan Dam Reservoir

Dokan dam	Average	Maximum	Minimum
Storage (m3)	1823014606.22	6761000000.00	692000000.00
Elevation (m)	481.39	511.00	469.00
Controlled Release (cms)	337.04	1464.75	9.85
Uncontrolled Spill (cms)	27.18	2091.26	0.00
Power Head (m)	71.21	99.19	59.18
Hydraulic Losses (m)	0.47	2.21	0.00
Energy Generated per Time Step (MWh)	1278.69	8311.81	0.00
Power Generated (MW)	53.28	346.33	0.00

Table 3. Statistical Analysis of The Elevation Water Level, The Storage And Hydroelectric Power Generation

parameters	average	skew	kurt	min	max
elevation	481.3883	0.263254	-1.30653	469	511
storage	1.82e+09	0.812108	-0.16071	6.92e+08	6.76e+09
power	50.5941	-0.51647	-1.13823	0.00	351.26

The calculated natural operating curve (Calculated Rule Curve) for the Dokan Dam reservoir was derived through the simulation process. A comparison between this curve and the original designed operating curve revealed a significant operational difference, leading to the conclusion that the original curve could not be fully relied upon. The design specifications of the Dokan Dam reservoir are illustrated in Figure 10.

The primary reason for this discrepancy is that the Dokan Dam was originally designed solely for irrigation purposes (Dokan Dam) [34]. However, in 1982, a hydroelectric power station was constructed, shifting the primary operational objective from irrigation to hydropower generation. This transition ultimately altered the reservoir's operating curve, necessitating an adjustment in the dam's management strategy.

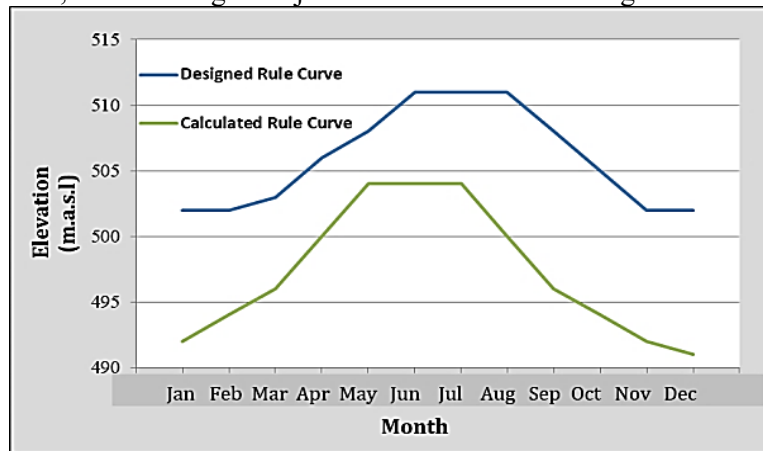


Figure 14. Comparison Between the Calculated and Designed Operating Curve for The Dokan Dam Reservoir

5. Conclusions

By evaluating the model's performance and comparing its outputs with recorded data, the study found a strong correlation, indicating that the model effectively represents the real system with high efficiency.

The analysis of 30 years (1980–2010) of historical daily flow data for the upstream stream of the Dokan Dam revealed significant changes over time, suggesting that the flow series is not homogeneous. This indicates that the Dokan Dam may struggle to meet future water demands in the region.

Furthermore, the study confirmed that HEC-ResSim 3.0, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, performed effectively in simulating monthly discharges and assessing the behavior of hydraulic structures and dams. As a result, the HEC-ResSim model was successfully used to construct the Dokan Dam reservoir simulation, demonstrating its capability for enhanced water system analysis in this study area.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Author Contributions

All authors proposed the research problem. In addition to the author Laith B. Al-Badrane, to collected the recent articles and organized them into simple forms. Author Maha A. Abdullah and Muqdad Al-Hamami verified the recommendation in the proposed work. All authors discussed the results and the final version of this paper.

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Notation list

Abbreviations	Meaning
HEC-ResSim	Hydrologic Center-Reservoir Simulation Model
EL	Water Reservoir Elevation
CMS	Cubic Meter per Second
MWH	Megawatt per Hour
M. A. S. L	Meters Above Sea Level

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