Analysis of water flow during the drought and flood seasons case study: The Mosul dam, Iraq

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Abstract. Mosul Dam is a structure facilitated to create a reservoir or a human-made lake named Lake Dahuk. Tigris river is the upstream water supply of the Mosul dam. The dam located at the western of Mosul city, the center of the governorate of Nineveh in the north of Iraq. The only drawback of the dam is the position; it is built on unstable karst ground. This worry situation led to take serious efforts and treatment decisions since the occupation of Iraq in 2003. Unfortunately, no concrete news till now whether the dam is safe or not and what is the prudential supervision needed. The data of this research are obtained from the Iraqi ministry of water resources/Mosul dam department. Schedule reports and 442 monthly data values have been monitored using advanced electronic instruments and technical programming, under experience engineers and special supervisors within the period 2000-2016. The objectives of this study are; Analysis the water flow during the drought and flood seasons, also to study the impact of the Ilisu dam on the Mosul dam efficiency. In addition, this analysis gives the answers to the puzzling questions and probably hundreds of researches concerns. It was noticed that within the period 2009 to 2015 the monthly inlet water discharge values are the same values of the outlet discharge. And the highest value observed of the water level achieved by the dam in the year 2002 is 329.55 m above means sea level, while the less value is 287.89 m in 2011. In addition to the continuous operation of foundation concrete grouting, it is highly recommended to increase the depth of the grouting. Finally, the Ilisu dam has no direct impact on Mosul dam efficiency.

Keyword: Mosul Dam, Ilisu Dam, drought and flood seasons, inlet and outlet water quantity

1. Introduction
Mosul dam built to seize the Tigris inlet water through a wide-land of earth named lake Dahuk, then control the water stored in the reservoir to the outlet water flow at the time of low water flow season in
A specific discharge rate. In fact, the water released used for many important demands; irrigation, power supply, industry, and human social implementations. In general, besides these benefits, the ecological and environmental impacts are considered as disadvantages of a dam [1].

A serious study has been investigated the general circumstances of the Mosul dam, and how the serious situation is. A case study selected by Hindreen to conjecture a flood catastrophe scenario caused by a probable dam break caused by the foundation base, using the GE program and digital elevation model at the maximum operation level 330 m above mean sea level. He found that approximately 237 km² of Mosul city will be submerged within 7 hours [2].

A predicted study model was done by Nasrat Adamo and Nadhir Al-Ansari. It is a computer programming simulation model. The authors produce several recommendations in case of dam failure; People rescue procedure and emergency plan details to minimize the life loses downstream of Mosul dam [3]. The same authors have another study issued in the same journal volume. The study showed that the concrete grouting procedure of the foundation cavities cannot be considered as a permanent solution. A serious sought for another solution is highly recommended [4].

Another prediction study of flood disasters by Thair and Anas. The floodplain will cover approximately 250 km² and cause disaster damage to the areas downstream of the dam [5].

While, Younis and Ali, predicted the worst scenario of the possible floodplain caused by Mosul dam failure. Mosul city will be completely submerged within two hours after the dam break. The results are compared with previous prediction scenarios, they found that Badush dam has a perfect option and location to fend off a floodplain wave and to protect the downstream cities of Mosul dam [6].

Researchers from the Lulea University of Technology-Sweden, are interested also in this case. The study result suggested building another dam located at the downstream of the Mosul dam [7]. Meanwhile, other researchers confirm the stability of the dam and they excluded the idea of a dam collapse. They have many of evidence; the two major floods encountered the dam in 1988 and 1994, no significant cracking was noted along the embankment, also no sinkholes detected in the Dahuk lake reservoir upstream the dam using echo-sounding surveys [8].

The methodology and data inquired in this study from the Iraqi Ministry of Water Resources of Mosul dam to improve the performance and solve future problems. It is noteworthy to mention that no surveys focused on the water inlet and outlet discharge in detail to make a comparison image during the drought and flood seasons through the years 2000-2016 and the latitude water elevations of the dam, also the impact of Ilisu dam on upstream of Mosul dam.

2. Mosul dam

2.1. Location of Mosul dam

Satellite image figure 1 taken from Quick Bird satellite 2015 with resolution 0.6 m and figure 2 indicate the location of the dam 60 km (45 mi) north of Mosul, Nineveh Governorate, Iraq, where the location in Tigris river forms a lake and surface area about 420 km².

**Figure 1.** Satellite image from quick bird

Mosul dam built on a karst foundation which is formed from gypsum dissolved of soluble gypsum rocks [9]. The topographic characteristic feature of the dam lets a water sinking stream enters through the soil
fissures and sinking holes to reach the underground cavities, this caused probably an internal potential erosion, figure 3.

![Figure 3. The features of a karst dam system.](image)

In September 2006, according to the United States Army Corps of Engineers report, considered Mosul dam as a dangerous dam in the world. This report gives further concerns over the possibility of a dam collapsed scenario, and the flood that might be happened in Mosul city [10], also to calculate the time period needed before the flood water reach Baghdad the capital of Iraq after the sudden failure of the dam. This could consider a worse situation happened ever, declaring a state of emergency is urgently required to eliminate the total estimated death and keep the person's health, security, property, or environment safe. This report confirmed by US SIGIR on October 30, 2007 [11], deems the dam's foundations to be unsafe [12]. In fact, this report has become binding on the UN coalition to maintain the integrity of the dam.

2.2. Characteristics of the Mosul dam

The construction of the Mosul dam began on January 25, 1981, collect the water in the lake Dahuk started in June 1984, and keep filling till the spring of 1985, while the dam started actual operation on July 7, 1986, with construction an approximation cost of 1.5 billion dollars. The specification of the Mosul dam detailed in table 1 [13]. The spillway service located on the east side of the Mosul Dam, five gates control the maximum capacity flow of 13x10^3 m^3s^{-1}. Also, the emergency spillway capacity fuse 4x10^3 m^3s^{-1}[14]. Four turbine power supply generators type Francis functioned to produce eco-friendly electrical sources for multiple purposes uses [15].

| Specifications                  | Details             |
|---------------------------------|---------------------|
| Height of dam                   | 113 m               |
| Length of the top dam           | 3600 m              |
| Width of the top dam            | 10 m                |
| Total Level of the top dam      | 341 m M.S.L         |
| Operation level                 | 330 m M.S.L         |
| Store volume                    | 11.11 billion m³    |
| The area in Operation level     | 380 km²             |
| Highest level                   | 338 m up M.S.L      |
| Store volume highest level      | 14.53 billion m³    |
| Maximum of operation level      | 335 m               |
| Living store in maximum operation level | 8.16 billion m³  |
| Dead store in maximum operation level | 2.95 billion m³ |

Investigation study by Issa et al. in 2013 to record the maximum and minimum average flow of Mosul reservoir within the years 1986-2012, it is obvious that September considered a dry month, while April month reach the highest flow, figure 4.
A previous records of the Tigris river within the years 1930-2012 of the maximum and minimum flow of 3500 m$^3$s$^{-1}$ and 90 m$^3$s$^{-1}$ in April 1954 and September 1986, respectively, figure 5 [13].

![Figure 4. Average monthly inlet and outlet flow of Mosul Reservoir. [13]](image)

![Figure 5. Tigris river inlet flow per month [13]](image)

2.3. Impact of Ilisu dam
The Ilisu dam is a rock dam covered by a reinforced concrete face, located at the Tigris river south Turkey, functioned to provide electrical power of $1.2 \times 10^3$ Mega Watt and control 10.0 billion m$^3$ of floodwater [16]. The construction of the dam began in 2006 [17], and the order to the supervisors to start filling the reservoir of the Ilisu dam in July 2019 [18].

The earth excavations started in May 2011 [19]. A ceremony celebration held in August 2012 announced the Tigris River conversion [20]. The prospective date of the project complete in 2015 [21], in fact, 96% of the works finished in June 2017 [22] and the complete construction project in 2018 [23].

Due to the water shortages in Iraq, the reservoir impoundment date postponed until the end of 2019 [18]. Meanwhile, Mosul dam witnessed a water shortage [24] of 5 billion m$^3$ in comparison with its levels in the same period of the last year [25], shuttle connections between both Iraqi and Turkish government. The warrior includes Mosul dam, but not limited, as the Tigris river had the lowest water level in the south of Iraq. The flow discharge decreased by approximately 50% than the total Tigris water share [26]. As a result, the marshes have been dehydrated, affecting the environment and the ecological system [27]. To make matters worse, the emergence of desertification signs in other parts of Iraq [28] due to the lack of rainfall in the winter season [29] that would reduce the agricultural areas [30]. By logic, the Ilisu dam has a direct impact on the Mosul dam reservoir intake and the downstream flow especially the distance of the Tigris River between the Ilisu dam and Mosul dam is approximately 200 km, table 2 and figure 6.

| Table 2. History of Ilisu dam construction date details |
| --- |
| **Details** | **Dates** |
| The construction of the dam began | 2006 |
3. Iraq climate
Drought is a random natural phenomenon that emerges from a large deficiency in precipitation. It is the costliest natural disaster in the world and affects a very large number of people every year [31]. However, the summer is the hot season with a dry dusty wind of 80 km/hr. with two types of winds; southern winds blowing within April-June and the south-east wind blowing within September-November. The temperature degree almost 47 ºC in June-August. While the flooding is the overflow of the stream at the river edges than the normal circumstances water level. The flooding almost caused by continues and/or frequent rainfall approximately 40 cm/year to reach 100 cm/year in some places near the mountainous lands. Habitual rainfall and fully saturated soil increase the probability of floodplain. In winter season months (December- April), precisely in January, the temperature degree drops below 0 ºC.

4. Results and discussions
The water inlet (inflow) is the water that stems from the source of the Tigris river acquired from Turkey. While the water outlet (outflow) means the water drainage out from the dam used for irrigation and also used for electricity generation.

The data of this research are obtained from the Iraqi ministry of water resources/Mosul dam department. Schedule reports and 442 monthly data values have been monitored using advanced electronic
Instruments and technical programming, under experience engineers and special supervisors within the period 2000-2016. The authors will use this data to analyze the monthly inlet and outlet flow. In April 2003, the maximum inlet and outlet flow values are 2436 m$^3$s$^{-1}$ and 1949 m$^3$s$^{-1}$. Also, in August 2014, the minimum inlet and outlet flow value is 75 m$^3$s$^{-1}$. Inequality in values between the flood and drought season almost 32 times, see table 3.

### Table 3. Max. and min. monthly inlet and outlet flow through the years 2000-2016 [32]

| Months   | Discharge m$^3$s$^{-1}$ | Minimum | In year | Maximum | In year |
|----------|-------------------------|---------|---------|---------|---------|
| January  | inlet flow              | 215     | 2001    | 1115    | 2006    |
|          | released flow            | 157     | 2000    | 1020    | 2013    |
| February | inlet flow              | 194     | 2011    | 1115    | 2006    |
|          | released flow            | 157     | 2000    | 1020    | 2013    |
| March    | inlet flow              | 530     | 2000    | 1490    | 2004    |
|          | released flow            | 140     | 2001    | 1185    | 2013    |
| April    | inlet flow              | 502     | 2014    | 2436    | 2003    |
|          | released flow            | 115     | 2001    | 1949    | 2003    |
| May      | inlet flow              | 400     | 2014    | 1465    | 2011    |
|          | released flow            | 150     | 2000    | 1360    | 2007    |
| June     | inlet flow              | 175     | 2014    | 620     | 2002    |
|          | released flow            | 175     | 2014    | 745     | 2003    |
| July     | inlet flow              | 110     | 2001    | 330     | 2013    |
|          | released flow            | 120     | 2014    | 605     | 2004    |
| August   | inlet flow              | 75      | 2014    | 298     | 2013    |
|          | released flow            | 75      | 2014    | 648     | 2002    |
| September| inlet flow              | 78      | 2009    | 190     | 2006    |
|          | released flow            | 78      | 2009    | 597     | 2002    |
| October  | inlet flow              | 78      | 2010    | 235     | 2007    |
|          | released flow            | 78      | 2010    | 524     | 2003    |
| November | inlet flow              | 95      | 2000    | 690     | 2007    |
|          | released flow            | 105     | 2011    | 555     | 2007    |
| December | inlet flow              | 122     | 2000    | 502     | 2013    |
|          | released flow            | 130     | 2011    | 502     | 2013    |

The monthly values within the years 2009-2015, the inlet water flow are the same as the values of the outlet water flow. The scientific explanation of this analysis means that all the water quantity comes from the Tigris river upstream the Mosul dam go through the dam spillway directly to the downstream without any obstruction.

Both the inlet and outlet flow reached the maximum value of 1330 m$^3$s$^{-1}$ in January 2010. While the minimum inlet and outlet water flow values are 157 and 142 m$^3$s$^{-1}$ in 2011 and 2000, respectively. Except for the monthly values in the years 2001, 2005 and 2007, the inlet flow values are more than the outlet flow values.

Figure 7 shows the monthly inlet and outlet flow water for the twelve months between the period 2000-2016. The horizontal axis represents the years 2000 to 2016 and the vertical axis represents the flow discharge in m$^3$s$^{-1}$. 
Figure 7. The monthly inlet and outlet water flow within 2000-2016
February considered a winter month season. Almost, the annual rainfall occurs between November and April, but the heavy rainfall that happened in February makes the flow irregular. The turbulence flow starts from this month till the end of May. In this month the minimum inlet and outlet values records are 194 m³s⁻¹ and 157 m³s⁻¹ in the years 2011 and 2000, respectively. On March 20, the winter season ends, also the ends of rainfall and the start of a pleasant spring season on March 21, the date of capturing snowmelt from Turkey. The maximum inlet flow is 1490 m³s⁻¹ in 2000 which is more than the flow inlet of January by 12%. And the maximum outlet flow is 1185 m³s⁻¹ in 2013. While the minimum inlet flow is 530 m³s⁻¹ in 2000 and the minimum outlet flow is 140 m³s⁻¹ in 2001. The highest mean monthly discharge occurs during April, it is a spring season come with a start of melting snow and the ground earth is fully saturated with rainfall water, the probability of flooding threaten is expected to happen in this month. The inlet flow reached the maximum value ever through the years 2000-2016, 2436 m³s⁻¹ this value monitored by the Mosul dam supervisions in April 2003. A comparison between the recent data with the data acquired since 1931, this value is less than the value 3514 m³s⁻¹ recorded in April 1954 [33]. While the minimum value recorded since 1931 is 75 m³s⁻¹ in August 2014.

May is the spring season month, the maximum inlet and outlet flow discharge values are 1465 m³s⁻¹ in 2011, while the minimum inlet and outlet values are 400 m³s⁻¹ and 150 m³s⁻¹ in 2014 and 2000, respectively.

June located between two seasons the spring and the summer. The drought starts from this month till the end of December. The inlet and outlet curves of these months are semi steady and no sudden jump or turbulence monitored through the years 2000-2016.

The maximum design flood limit above the mean sea level of the Mosul dam is 335 m, while the ultimate latitude value above m.s.l is 338 m. In case the water level reaches the ultimate latitude value then the water inside the reservoir should be evacuated immediately through the spillway downstream gates, otherwise, the dam could be threatening by collapse fears. The maximum water level reached during the period 2000-2016 is 329.5 m in 2002, while the minimum level is 297.89 m in 2011, figure 8. Within the years 2006-2016 a constant water level of 319 m above mean sea level. This constant level was decided at the beginning of 2006 by the authority of the Ministry of Water Resources to limit the maximum operation water level to elevation 319 m above m.s.l instead of elevation 330 m. This operation is a precautionary measure in order to limit the dangers facing the dam to reduce the risk about the seepage under the dam and the possibility of the formation of new sinkholes [32].
5. Conclusions and recommendations

- Mosul Dam is still considered unstable due to the nature of geological soil foundation.
- The recent media fuss gave a positive reaction than the real situation of the dam is, to push authorities and government to ensure the prudent operation and keep it safe.
- Periodic investigations and studies are recommended.
- In addition to the continuous operation of foundation concrete grouting, it is highly recommended to increase the depth of the grouting.
- Also, an alternative plan is urgently needed to match the feasibility studies.
- Finally, the Ilisu dam has no direct impact on Mosul dam efficiency.

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