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ANALYTICAL STUDY OF SEDIMENT EVOLUTION IN THE LAKE OF THE FOUM EL GHERZA DAM (BISKRA, ALGERIA)

ETUDE ANALYTIQUE DE L'EVOLUTION SEDIMENTAIRE DANS LE LAC DU BARRAGE FOUM EL GHERZA (BISKRA, ALGERIE)

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ABSTRACT

The research carried out as part of this work aims to provide answers to the rhythms and processes of sedimentation in the lake of the Foum El Gherza dam. Based on the bathymetric surveys carried out by the National Dams Agency in the Foum El Gherza dam, we have shown the temporal evolution of the silting up of the dam. As a result, the filling of the lake exceeded 70% of its initial capacity as of 2007. Despite the de-silting of the dam by dredging, the dam is in critical condition. Dredging operations must continue in the short term to extend the life of the structure.

Keywords: Dam, Flood flow, Dredging, Siltation, Bottom emptying, Sediment.

RESUME

La recherche menée dans le cadre de ce travail a pour objectif d'apporter des éléments de réponse quant aux rythmes et aux processus de sédimentation dans le lac du barrage Foum El Gherza. Sur la base des levés bathymétriques effectués par l'agence Nationale des Barrages dans le barrage de Foum El Gherza, nous avons montré l'évolution dans le temps de l'envasement du barrage. C'est ainsi que le comblement du lac a dépassé les 70% de sa capacité initiale à partir de l'année 2007. Malgré le desenvasement du

barrage par le dragage, le barrage se trouve dans un état critique. Les opérations de dragage doivent continuer encore a court terme pour allonger la durée de vie l'ouvrage.

Mots clés : Barrage, débit de la crue, dragage, envasement, vidange de fond,

INTRODUCTION

Today, Algeria has 74 large dams in operation with a total capacity of 8.5 billion m^3. Following the phenomenon of erosion which is very intense throughout the territory of North Africa, these dams are threatened by the phenomenon of siltation. The high concentrations of fine particles cause the appearance of density currents in the dam lakes (Remini et al, 2015; Remini and Benfetta, 2015). In the early 2000s, the siltation rate was 32 million m^3/year (Remini, 2004a). In 2017, this value doubled, resulting in a siltation rate of 65 million m^3/year (Remini, 2017). However, Algeria has acquired a great deal of experience in the fight against siltation. All the siltation techniques have been applied in severely silted dams. Algeria is among the few countries in the world that uses the tapping density currents. The practice of racking during floods in the dam Ighil Emda (Algeria) is a good example, since his life was multiplied by three. Another technique has been applied to about ten dams, and that is the dredging technique. (Remini and Hallouche, 2004b). In recent years, the hydraulic services have solved the place of discharge of the silt. Today, they no longer discharge mud downstream of the dam into the wadi, they have built mud storage ponds upstream of the reservoir, and the water returns to the reservoir. This closed system was used for the clearing of the dams of Foum El Gherza (Remini et al, 2015, Remini, 2019) and Bouhanifia (Remini, 2019). Only, this operation requires the space for pools. To solve this problem, the recovery of the mud in the agricultural or construction field remains the only way out (Labiod et al, 2004; Remini, 2006). The Foum El Gherza dam is a dam that is seriously threatened by siltation. Our study is interested in the evolution of siltation at this dam.

STUDY REGION AND WORK METHODOLOGY

Located 400 km as the crow flies south-east of Algiers, it is the only dam built on a wadi descending from the Aurès during the period 1945-1962. It was preceded, in 1847, by a small diversion structure accompanied by an underground gallery on the right bank, which has now completely disappeared (Merarhemi, 1995). But the reservoir dam project was only proposed in 1902, following an exceptionally violent flood on the night of September 15 to 16, 1902. The first dam, 3 m high, completed in 1918, was replaced by the current one, put in water in 1949.

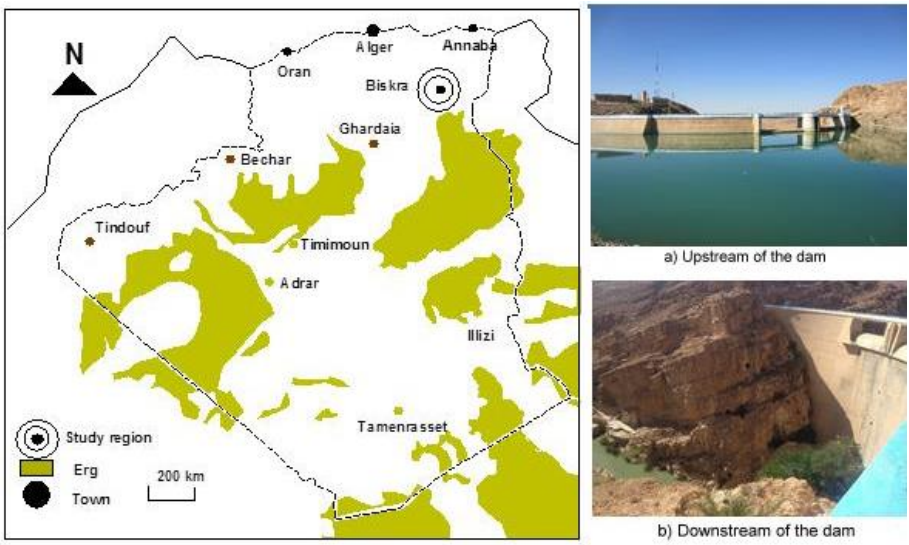


Figure 1: Location of the Foum El Gherza dam

The choice of the Foum El Gherza Dam in Algeria, as a place of research, depends on several specific factors. This dam is exposed to strong sedimentation due to the erosion of the watershed. This is how the accelerated sedimentation of the reservoir was evident from the start of construction of the dam, the upstream cofferdam having been completely filled in two years (1948-1950); subsequently, it caused a rapid rise of the silt roof, more than 35 meters in 40 years of operation, which represents a silt volume equal to 18.5.millions m^3. The estimate of the capacity of the reservoir in 1995 at 24 Hm^3, i.e. a filling of more than 50% (Remini, 2010). During a campaign of bathymetric surveys of the dams in operation, initiated by the ANBT (The Algerian National Agency for Dams and Transfers) in 2007, the results clearly show the decrease in the storage capacity of the Foum El Gherza dam over time and the siltation rate has reached 72%. The watershed of this dam, this one of Oued El Abiod has its source in Aurès (Mitard, 1941), its basin is characterized by two particular morphological parts (fig. 2). The head of the basin is a mountainous part; this part is formed by the meeting of several torrents descending from the steep slopes of Jebel Chelia (2326 m) and Jebel Ichmoul (2100 m) (Benkhaled and all, 2013). The steep slopes of the mountainous landforms of the watershed, also, the sudden and heavy rainfall, promote erosion of slopes and rapid transport of eroded materials downstream. The downstream region of the basin, which extends from El Habel to the mouth of the Oued El Abiod (Foum El Gherza dam), borrows from the landscapes of the Saharan plain, which will induce a high production of easily mobilized materials (Fig. 3).

The watershed draining an area of 1300 km². Despite its small size, it can be qualified as a complex given the physical parameters that determine it (topography, pedology, hydrography, etc.).

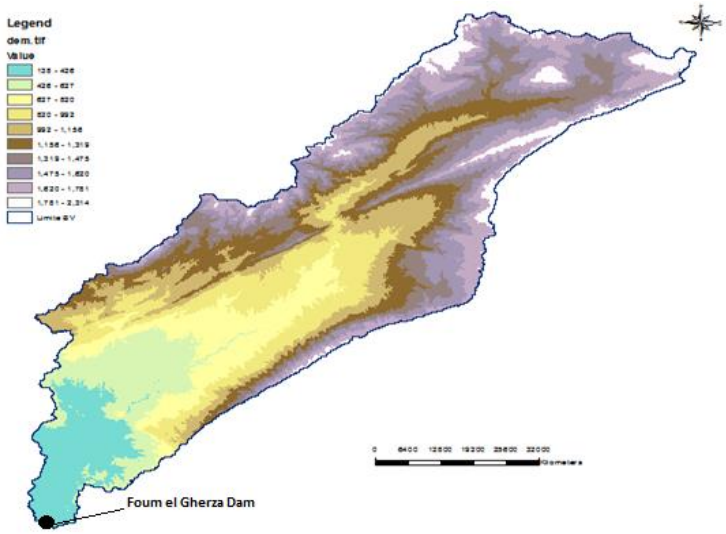


Figure 2: Relief map of the Oued el Abiod watershed

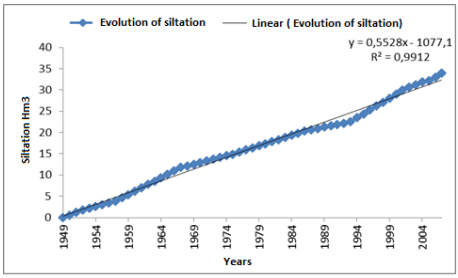
Figure 3: Soil degradation downstream of the watershed (Photo. ANBT-Foum El Gherza Dam)

RESULTS AND DISCUSSION

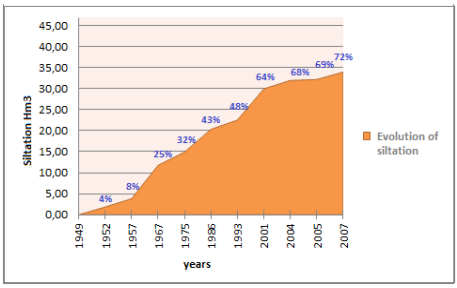
Evolution of the silting up of the dam

We will focus on the volume losses to obtain a good quantification of the volumes of sediment arriving in the dam lake. From the available data, Figure 4 (a and b) shows the change in the volume of the dam's silt between its commissioning and the last known reading. Graph (a) illustrates the difference between the initial volume of the dam which is 46.844 Hm^3 and the volume of the silt; we observe that the volumes lost are very large. However, its interpretation requires further presentation. Indeed, the graph (b) represents the adjustment of the evolution of the silt volume, while the slope is important (0.55) shows the high speed of the silt evolution in the dam.

We note that the capacity is sharply reduced each year. It is therefore necessary to question the causes of such a rapid filling in jeopardizing the operation of the dam.



a) Linear evolution of the silt.



b) Evolution of siltation rate

Figure 4: Siltation for the Foum El Gherza dam since its commissioning (ANBT Data)

Analysis of inter-annual siltation

Taking an interest in the sediment volumes entering the dam lake makes it possible to account for the sediment production in the part of the basin upstream of the structure. Functioning as a sediment trap, the latter is a good indicator of soil degradation in the watershed. Table 1 shows the state of siltation by presenting the mean annual siltation for periods represents the annual interval between two bathymetric surveys as well as the annual mean siltation volume for the entire period studied from 1949 to 2007 which is of 0.585 Hm^3 and with a total siltation rate of 72.47%. We thus note the volumes of the mud are very heterogeneous varying between 0.22 Hm^3 to 0.927 Hm^3.

The siltation rate values are here scaled from 1.48% for the 2004-2005 periods to nearly 30.51% for the 1993-2001 periods. However, losses in global reservoirs presented in the literature are of the order of 0.2% (for American reservoirs and in the Maghreb region) and 2 to 3% for Chinese reservoirs (McCully, 2001; Remini, 2009) this clearly shows the extremely fast speeds of the siltation of the Foum el Gherza dam.

Table 1: Average siltation rate of the Foum El Gherza dam (ANBT Data)

Period studied	Initial capacity Hm^3	Average annual intake Hm^3	Siltation of the period Hm^3	Siltation rate%	Average annual siltation Hm^3
1949 (commissioning)	46,844	6,161	0	0	0
1949-1952	44,995	20,547	1,849	3,95	0,616
1952-1957	43,008	13,805	1,988	4,42	0,398
1957-1967	35,068	30,305	7,940	18,46	0,794
1967-1975	31,925	19,416	3,143	8,96	0,393
1975-1986	26,519	19,412	5,405	16,93	0,491
1986-1993	24,313	20,245	2,206	8,32	0,315
1993-2001	16,896	15,629	7,417	30,51	0,927
2001-2004	14,893	44,469	2,003	11,85	0,668
2004-2005	14,673	40,536	0,220	1,48	0,220
2005-2007	12,904	22,009	1,769	12,06	0,885
1949-2007	12,904		33,940	72,45	0,585

Figure 5 relates the initial capacity of the dam to the annual average siltation rates for each period studied. We then see the strong annual loss of capacity for the period 1993-2001 with a high siltation rate of 30.51%.

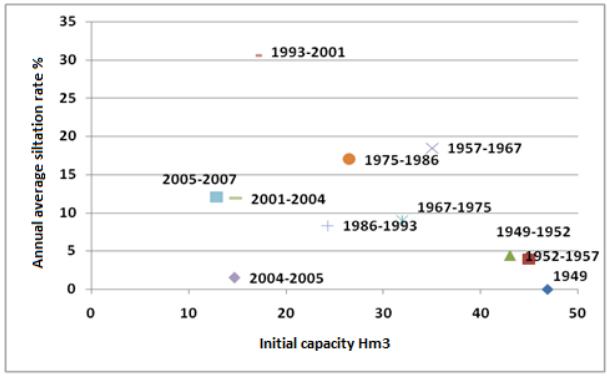


Figure 5: Relationship between initial capacity and annual average siltation rate. (ANBT Data)

The representation of the initial capacity and the annual average siltation does not make it possible to arbitrate the heterogeneous distribution of the volumes lost for the different periods for each other; therefore, we put a relation between the average annual intake and average annual siltation for the periods studied.

Figure 6, which show the relationship between the average annual inflow and the average annual siltation of the dam. The relationship appears less linear even if for small inputs there is a large quantity of silt deposited at the dam compared to larger inputs. We can establish the following observation:

- A period with annual average siltation equal to 0.22 Hm^3 for a significant contribution compared to the other periods (40.536 Hm^3): 2004-2005;
- A period with a very high average annual siltation equal to 0.927 Hm^3 for a smaller contribution compared to the other periods (15.629 Hm^3): 1993-2001;
- 5 periods have annual average siltation of fewer than 0.616 Hm^3 for inputs between (13.805-20.245 Hm^3): 1949-1952, 1952-1957, 1967-1975, 1975-1986, 1986-1993;
- Finally, 3 periods have mean annual siltation values between 0.668 and 0.885 Hm^3 for inputs between (22.009 and 44.469 Hm^3): 1957-1967, 2001-2004, and 2005-2007.

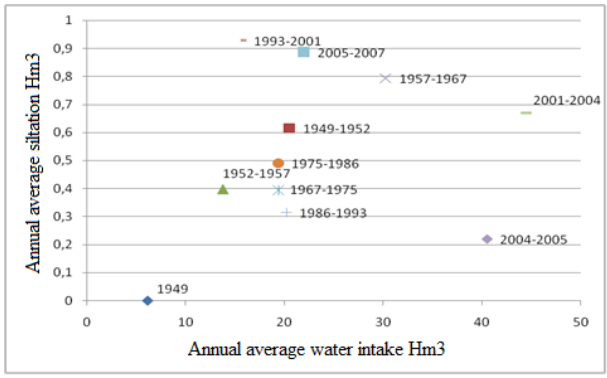


Figure 6: Relationship between the average annual water intake and the average annual siltation (ANBT Data)

Relation of flood flow and siltation

After having described the overall evolution of sedimentation in the Foum El Gherza dam allowing highlighting the major trends, in addition, the contribution of the flood represents 29% to 75% of the contribution of the dam for the different periods studied (fig. 7). Therefore, this part is more specifically concerned with the study of variations in sedimentation rates as a function of flood flow. The analysis is based on data from the various bathymetric surveys carried out and the flood flow data recorded at the dam level, will make it possible to determine the relationship between the volume losses of the dam as a function of the flood flow.

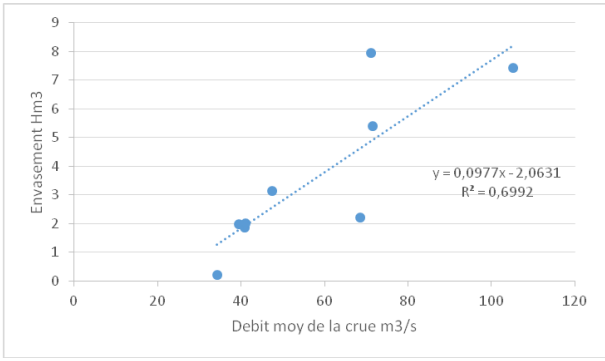


Figure 7: Relationship between the inflow of the flood and the annual inflow by period. (ANBT Data)

Figure 8, which shows the relationship between the siltation volume and the flood flow, shows the increase in siltation volume as a function of the flood flow in more or less regular periods. For the periods 1952-1957, 2001-2004, 2004-2005, 1949-1952, 1967-1975, 1975-1986 and 1993-2001, we then see the strong correlation between the siltation volumes and the flood. On the other hand, for the period 1986-1993 with the average flow of the flood 68.56 m^3/s, the siltation volume lower compared to the period 1967-1975 having the flow of the flood of 47.37. In addition, we note that for the period 1975-1967 there is a higher siltation volume than the others.

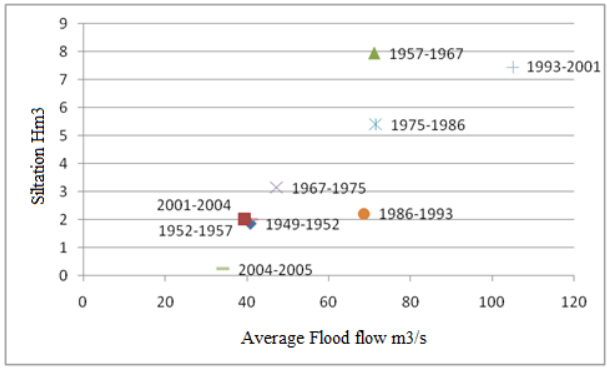


Figure 8: Relationship between average flood flow and siltation by periods (ANBT Data)

Extraction of sediment in the Foum El Gherza dam

The removal of the silt is a delicate and difficult operation, which very often requires that the reservoir is out of service, which is practically impossible. In the case of the Foum El Gherza dam, the extraction of sediments is carried out by two methods: dredging and bottom emptying (fig. 9 and 10). We can see from the figure below 6 that

many bottom drains were carried out to reduce the volume of sediment deposited in the dam lake, thanks to the bottom valve 23.663 Hm^3 of silt were evacuated from 1949 until 2007 (fig. 11). Unfortunately, the valve was blocked by silt for certain periods, it is quoted, for the period 1982 until 1989, the valve was blocked (Remini, 2010). Although the dredging operation is excessively long and expensive, Algeria carried out two dredging operations of the Foum El Gherza dam, the first taking place from 2002 to 2009 and the second which was started practically in 2016.

Figure 9: Dredging operation in the Foum El Gherza dam (Photo. ANBT-Foum El Gherza Dam)

Figure 10: Extraction of sediments in the Foum El Gherza dam By bottom drain (Photo. ANBT-Foum El Gherza Dam)

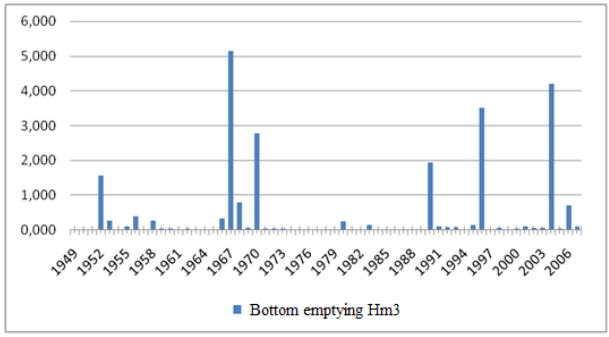


Figure 11: Sediment extraction by bottom emptying in the Foum El Gherza dam (ANBT Data)

CONCLUSIONS

This study gave us an analysis and illustration of the evolution of the siltation rate at the level of the lake of the Foum El Gherza dam during the period 1949 (commissioning) until 2007. This research was based on data collection. Main data on sediment volumes deposited in the Dam Lake, annual inflows, and flood inflows to be able to analyze the rates and rates of sediment deposition. These data also made it possible to observe the evolution of trends over fifty-eight years. This study illustrates that the Foum El Gherza dam experiences very high sedimentation rates as a whole. It is then a question of understanding what explains these high variations. The analysis of the collected data shows quantitatively the relationship of the flows of the flood and the volume of the silt in the lake of the dam. Siltation rates can be even greater when high flood flows, these floods significantly alter the natural environment carrying large amounts of sediment that are deposited at the outlet (Dam Lake). Even if the causes of the strong sedimentation of the Foum El Gherza dam are well known (deforestation of the watershed, the morphology of the basin and climate actions), those in charge did not take the right solutions. Indeed, the technical procedures applied to clear the sediments deposited at the lake level of the dam are dredging and bottom emptying which is not effective in putting an end to this enormous sedimentation problem. These techniques are temporary solutions, or else, dredging is an expensive technique and takes a long time and bottom emptying is not possible if the valve is blocked. These solutions may focus on solving the problem at the downstream watershed level only. It is a question of finding comprehensive responses that will allow the reservoir to be managed harmoniously in the decades to come, taking into account both soil protection, water resources, and above all the populations who occupy these territories. The results of this research may also be useful as a working basis for future dams under construction.

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