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ZARDEZAS (ALGERIA): A DAM THAT IS SILTING UP?

ZARDEZAS (ALGERIE): UN BARRAGE QUI S'ENVASE?

***TOUMI A.*[1]*, REMINI B.*[2]**

[1] Département de Genie Civil et Hydraulique, Université de Guelma, Algérie,
[2] Département des sciences de l'eau et environnement, Faculté de Technologie, université Blida1, Blida 9000, Algérie,

toumiouaheb@yahoo.fr

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ABSTARCT

This article examines the phenomenon of the siltation of the Zardezas dam, located in the prefecture of Skikda. Investigations were carried out at the level of the dam as well as its watershed. Data from the bathymetric surveys were made available to us by the services of the National Dams Agency. The results obtained showed that over time, the capacity of the dam has greatly diminished and that currently does not exceed ¼ of its initial capacity. It should be noted that during the period: 2003-2006, the rate of siltation reached 0.4 million m^3/year. At the same time, a volume of 0.3 million m^3 was removed from the reservoir. The dam is silting and increasingly likely to be filled to 100%.

Keywords: Dam, Density current, Zardezas, Siltation, Capacity.

RESUME

Le présent article examine le phénomène de l'envasement du barrage des Zardezas, situé dans la wilaya de Skikda. Des investigations ont été effectuées au niveau du barrage et son bassin versant. Des données des levées bathymétriques ont été mises à notre disposition par les services de l'Agence Nationale des barrages. Les résultats obtenus ont montré qu'au cours du temps, la capacité du barrage a beaucoup diminué et qu'actuellement elle ne dépasse pas le ¼ de sa capacité initiale. Il est à noter que durant la période : 2003-2006, la vitesse de l'envasement a atteint 0.4 millions de m^3/an. En parallèle, un volume de 0.3 millions de m^3 a été enlevé de la retenue. Le barrage s'envase de plus en plus et risque d'être comblé à 100% à court terme.

Mots clés : Barrage – Courant de densité- Zardezas- Envasement – Capacité.

INTRODUCTION

The silting up of dams is a consequence of the disruption of the water erosion cycle. Once, man disrupts the natural progression of sediment after the completion of a dam, the particles will eventually settle to the bottom of lakes made by the dams. Over time, the successive deposits cause the abandonment of the structure. In Algeria, the siltation rate in 2000 was 32 million m^3/year (Remini and Hallouche, 2004a). In 2006, the siltation rate rose to 45 million m^3/year (Remini and Hallouche, 2007). On the other hand, in 2017 the siltation rate reached the value of 65 million m^3/year, i.e. an annual capacity loss of 0,75% (Remini, 2017). In parallel, technical fight against the silting of dams has been engaged for over a century (Remini et al, 2009). By going from preventive methods such as reforestation and watershed development to curative methods such as the withdrawal of density currents (Remini et al, 1995; Remini et al, 1997), the raising of dams (Remini, 2008) and the dredging of dam reservoirs (Remini, 2004). As the mud rejected will not be valued in the areas of agriculture, the problem of the place of sludge discharges will always be asked (Labiod et al, 2004; Remini, 2006). The siltation phenomenon is very well responded to in North Africa, which records very high values in soil erosion by surface water runoff. In Morocco, the Saboun dam, located in the Tangier area, the rate of sedimentation is around 2% per year. This loss of water from the total capacity of the reservoir is a direct consequence of severe soil degradation in the watershed estimated at 115 t/ha/year (Abdelaoui et al, 2002). Tunisian dams lose 0.5% to 1% of their capacity annually through sediment deposits (Ben Mamou and Louati, 2007). In another region of the world, in Indonesia and more precisely in Java, an average of 2 billion m^3 of sediments have been deposited in reservoir dams since their commissioning. Each year, a volume of 70 million m3 of silt enters the reservoirs of these dams (Boun Heng, 2013).

In this paper, we deal with the consequences of the siltation phenomenon on the Zardezas dam, which is located in eastern Algeria. The dam is silting up more and more despite the efforts of the dam maintenance services. Several solutions were tested, namely raising the dike and hydraulic dredging of the reservoir. However, the dam was not spared by the accelerated deposition of sediment in the reservoir.

STUDY REGION AND WORK METHODOLOGY

Characteristics of the study area

Located on the Saf-Saf River 350 km east of Algiers and 30 km south of the city of Skikda, the Zardezas dam provides irrigation for 1000 hectares of the perimeter of the Saf-Saf plain. and supplies drinking water to the city of Skikda and the municipalities of Zerdazas, El-Harrouch, Aïn Bouziane and Mzedj Edchich as well as the industrial zone and the Skikda refinery. Not to mention that the dam also regulates the flow of the Saf-Saf River to cushion the violent floods which generally occur during the autumn and spring seasons.

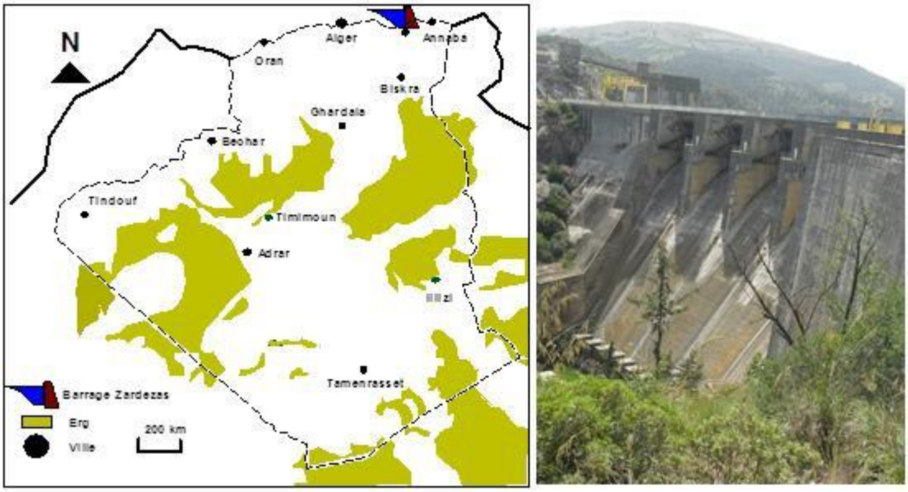


Figure 1:Location of the Zardezas dam (Remini, 2020)

Built during the period: 1926-1945, the Zardezas dam with an initial capacity of 15 million m^3 and a height of 74.2 m from the foundation. Its width at the base is 44 m while at the crest is 6.50 m, it has a length at the crest of 242 m. The normal level of the reservoir is at 197.30 and that of the highest water at 199.00. The Zardezas dam is a gravity type dam connected to an abutment on the left bank. Its storage capacity, initial before the elevation was 15 million m^3 and after the elevation became equal to 32 million m^3.

The dam is equipped with a spillway made in the central part of the dike which is made up of 5 segment valves, 4 of dimensions: 11m x 7m) each and one of dimensions: 15m x 7m. At the level of the dam of the Zardezas dam, 4 devasing valves 300 mm in diameter are installed on the 178 m coast. The bottom outlet is located at the lower part of the right bank of the dike, it is made up of two slide gates (1.80 m x 3 m) and a cofferdam (3.80 m x 4 m). The guard gate is installed at height 161.90 m and that of service at height 161.30 m while the cofferdam is installed at height 164 m. The flow discharged by the bottom drain, when the water level is at the normal level of the reservoir, reaches the value of 100 m^3/s. Figure 2 gives a general view of the dam of the Zardezas dam.

Figure 2: General view of the Zardezas dam (Photo. Toumi, July 2015)

The lake created by the dike is of the extended type, after the elevation it extends over an area of 193.4787 hectares at the normal level of the reservoir (197.30 m) and reaches 205.700 hectares at the highest water level (199 m). Figure 3 illustrates the shape of the Zardezas dam lake.

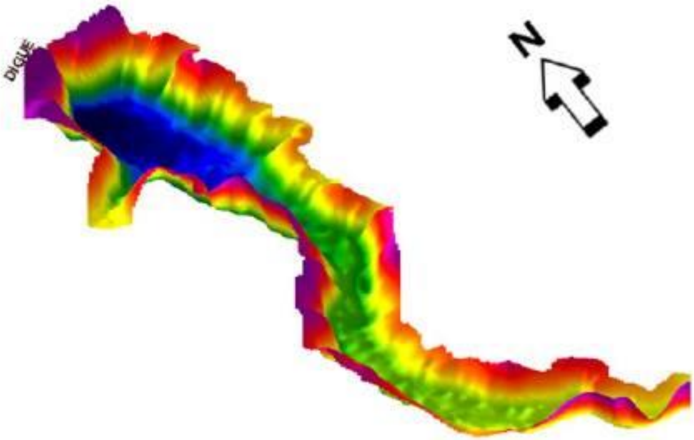


Figure 3: Shape of the basin of the Zardezas dam according to the bathymetric survey of 2003 (National Dams Agency, 2015).

Data used

Since the end of the raising of the dike in 1974 to the present day, three bathymetric surveys have been carried out, the first in 1986, the second in 2003 and the last in 2006. They made it possible to determine the storage capacity of this lake. dam and determined, at each survey, the quantity of sediment entering the basin of the dam. The 3 bathymetric surveys were carried out by:

The first bathymetric survey was carried out in 1986 by GEOKART. IMGW, Poland.

The second bathymetric survey was carried out in 2003 by FUGRO GEOID SAS, France. The third bathymetric survey was carried out in 2006 by AL.D.I.P.H, Algeria.

RESULTS AND DISCUSSIONS

Erosion in the watershed of Saf-Saf River

The region of Saf Saf is well known for these stormy rains of high intensity and short duration. Autumn rains are usually very loaded with fine particles. The annual variations in precipitation are represented by the histogram in Figure 4.

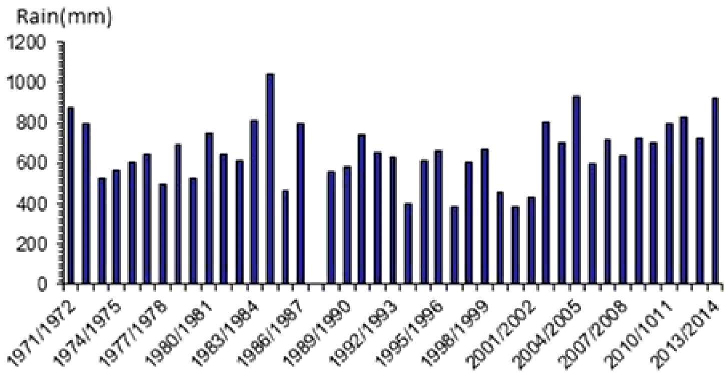


Figure 4: Variation over time in annual precipitation at the Zardezas dam pluviometric station, Algeria (Data of National Dams Agency, 2015).

This configuration shows that the region has gone through years with a large deficit and years with a large surplus, which characterizes the climate of the area. The interannual average rainfall is equal to 660 mm. However, sporadic floods occur in the region often very loaded with fine particles which can lead to a reduction in the storage capacity of the dam. Table 2 gives an overview of the floods recorded during the period: 2004-2012.

Table 1: The most significant floods recorded at the level of the Zardezas dam spillway, Algeria (Data: National Dams Agency, 2015)

Year	Liquid intake (Hm^3)	Average evacuated water flow (m^3/s)	Maximum flood flow (m^3/s)	Frequency of flood	Rain (mm)
11/11/2004	12,010	134	934	15	/
13/03/2007	9.748	113	180	15	33
02/02/2011	12.491	124	532	24	56.3
03/02/2011	0,259 0,248 0,075	72 69 20	72 (registered at 19.00 h)	24	56,3
04/02/2011	0,114 0,240	12	16 (registered at 10.00 h)	24	12,4
23/02/2012	9,616	105	251	24	50,2
24/02/2012	2,553	29,54	24	24	7,7
25/02/2012	1,304	15,09	20	24	5,2
26/02/2012	0,810	9,37	/	24	1,1

For example, the flood of March 13, 2007 which was recorded in the Saf Saf River drained an inflow of over 9.5 million m^3 with a maximum flow rate of the flood equal to 934 m^3/s. Water very laden with fine particles was brought back by the flood and deposited at the bottom of the dam as evidenced by the blackish color of the water (fig. 5).

Figure 5: Downstream of the Zerdezas dam. Flood of March 12 and 13, 2007 with a maximum flow rate of 180 m^3/s (Photo. National Dams Agency, March 12, 2007)

Other than heavy rainstorms and floods, the catchment area upstream of the Zardezas dam has steep slopes and soft and easily eroded rocks. This promotes erosion and the transport of fine particles torn from the watershed. Figure 6 shows a sheet slide and the steepness of the land slopes of the Zardezas dam watershed.

Figure 6: Sheet slide in the slope of the dam des Zardezas (Photo. Toumi, July 8, 2015)

Density currents in the Zardezas dam lake

Density currents appear in several dam reservoirs in Algeria such as Ighil Emda (Remini et al, 1995), Foum El Gherza (Remini and Maazouz, 2018; Remini et al, 2015), Guergar (Remini and Benfetta, 2015), Beni Haroun (Remini and Toumi , 2016) and Sidi M'hamed Ben Aouda (Remini et al, 2018). The Saf-Saf River drains floods very loaded with fine particles often exceeding the value of 100 g/l. This solid quantity comes from the erosion of the watershed upstream of the dam as well as the undermining of the banks. Once at the entrance to the lake from the dam, the contact of the flood waters and the lake triggers the formation of a density current. Aided by a very narrow canal-shaped lake, the density current flows easily over the lake bottom to travel a distance of 5 km from the dive point to the foot of the dam. The density current propagates in the form of a well-individualized blackish water beam under the water of the reservoir in a first section of 3.5 km and 250 m wide (fig. 7 and 8). In the second section of the 650 m wide lake, the density current propagates over a path of 1.5 km before reaching the drainage channels.

The Zardezas dam is silted up by density currents. Indeed in periods of flooding, the density current, once started at the diving point, it propagates over a distance of 5 km to reach the dam dike. But in cases where the fine particle concentration is low, the density current after a 3.5 km journey, vanishes and loses these sediments in the convergent (Fig. 9). The wide part of dimensions of 1.5 X 0.65 is the most silted part of the dam.

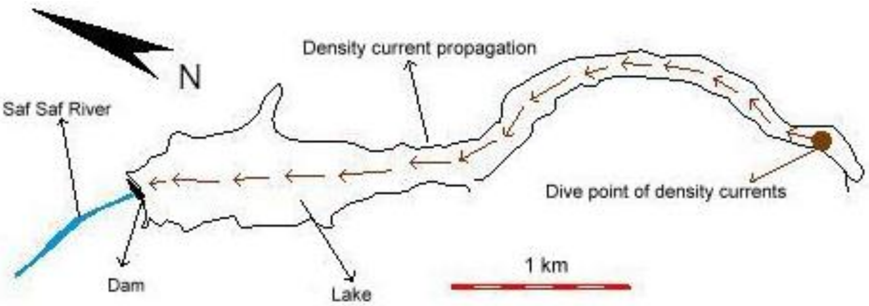


Figure 7: Propagation of density currents in the Zardezas basin (Scheme Remini, 2020)

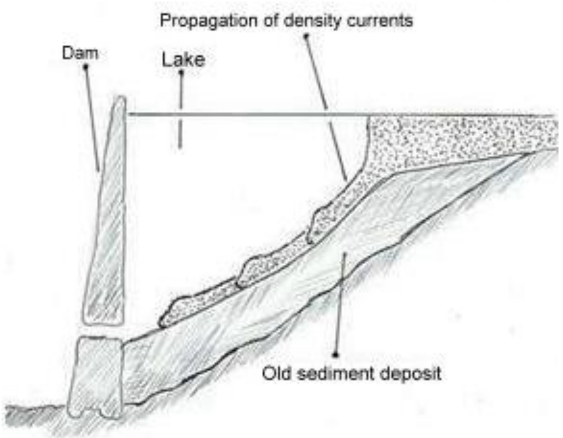


Figure 8: Probable diagram of the propagation of density currents at the bottom of the Zardezas dam (Remini diagram, 2020)

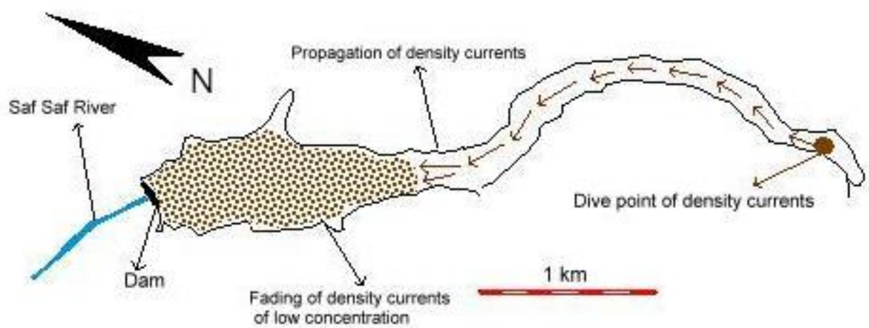
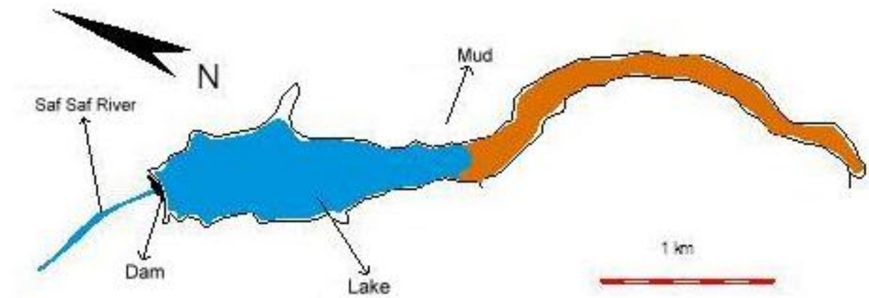


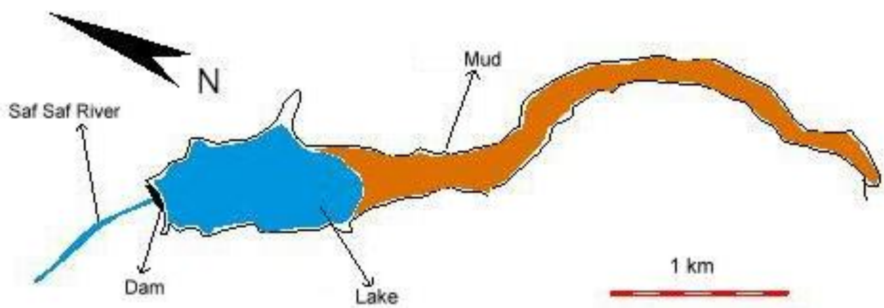
Figure 9: Division of the Zardezas basin into two parts: Canal of 3.5 km the lake of 1.5 km (Scheme Remini, 2020)

Evolution of siltation in the Zardezas dam

The disappearance of the density currents in the large part and the failure to open the drainage slits at the appropriate time promotes the settling of fine particles. These successive deposits of silt reduce the capacity of the dam. Thus in 1967, the dam with an initial capacity of 15 million m^3 could store only 9 million m^3 due to the problem of siltation. About 6 million m^3 of silt was deposited at the bottom of the dam. The first solution provided by the dam services is to raise the dike by more than 12 m to reach a volume of 32 million m^3 in 1974. But with the addition of sediments drained by density currents, the capacity of the dam relapsed to 16.5 million m^3 in 1986. A second solution to this silting up phenomenon was applied by the relevant departments in the early 1990s, was hydraulic dredging. In 2003, the capacity of the dam reached a volume of 18 million m^3 (fig. 10 a). In 2006, the dam's storage capacity fell again to reach 16.5 million m3 thanks to new solid inputs (fig. 10 b). During the period: 1990-2006, a volume of 10.3 million m^3 of silt was removed by the dredging technique. In 20 years of operation, the capacity has remained equal to 16.5 million m^3; the density currents drained the same volume of sediment de-silted by hydraulic dredging (fig. 11).



a) Surface of the dam lake in 2003 (Remini scheme, 2020)



b) Surface of the dam lake in 2006 (Remini diagram, 2020)

Figure 10: Evolution of the surface area of the Zardezas dam lake

Figure 11: State of the siltation of the Zardezas dam (Photo Toumi, January 25, 2017)

Change in the capacity of the Zardezas dam in 2003 and 2006.

Of the three bathymetric surveys carried out, there is a reduction in the storage capacity at the normal level of the reservoir. The explanation that can be given is that, despite the de-silted work that took place in this basin, the sedimentation rate is greater than that of de-silted. To dive into the context of the surface submerged in the reservoir as a function of the same level of the water body, we have plotted in figure 12 the variation of the surfaces submerged in the reservoir of the Zardezas dam, as a function of the height. of water in the basin and that for the three bathymetric surveys carried out successively in 1986, 2003 and 2006.

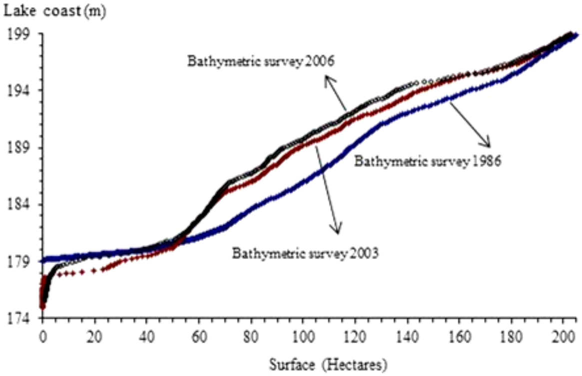


Figure 12: Variation of submerged areas depending on the coast, for the three bathymetric surveys carried out, at the Zardezas dam lake, Algeria (Data National Dams Agency, 2015)

The submerged surface in the Zardezas dam reservoir has undergone a major modification after 20 years of the first bathymetric survey. Indeed, the three curves can be subdivided into 2 branches. From level 174 to level 184 m, we notice an increase in the submerged surface compared to the initial one due to the dredging carried out in this area. Beyond the 184 m level, there is a decrease in the submerged surface compared to the initial one and that for the same level of the lake, this decrease can be justified by the modification that has undergone, over time, the initial shape of the bottom surface of the bowl. Take, for example, the highest water level, there is a decrease in the surface area occupied by water over time, based on the three bathymetric surveys carried out. Indeed, in 1986 the surface was 205 hectares, in the year 2003 was 202.58 hectares and in 2006 was 202 hectares that is to say until the year 2006 an area of more than 3, 60 hectares was lost due to the sedimentation of the basin. What is more attractive, that at the normal level of the reservoir (197.30), the submerged surface fell from 193.5 hectares in 1986 to 187.74 hectares in 2006, a decrease of 5.74 hectares? The decrease in the lake area of the dam is due to the increase in the area of the silt delta (the tail of the reservoir) (fig. 13).

Figure 13: The shape of the basin upstream of the Zardezas dam, Algeria (Photo Toumi, July 8, 2015)

To highlight the variation in storage capacity over time, we have shown in Figure 14 the variation in water volumes in the reservoir as a function of the heights for the three bathymetric surveys carried out.

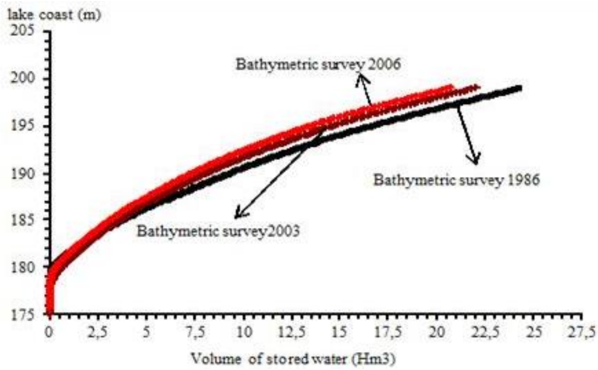


Figure 14: Variation in the volumes of water stored according to the coast of the lake in the Zardezas dam, Algeria (Data: National Dams Agency, 2015)

The difference recorded between the three curves testifies to the modification to the initial shape of the basin of the Zardezas dam. This change in shape is due to the material carried by the water and deposited in its bowl. The volume between the three curves is considered lost, because the silt has taken the place of the water. After 20 years of the first bathymetric survey and for the same level of the lake, there is a decrease with each bathymetric survey, in the volume of water stored in the reservoir of the Zardezas dam, this loss is undoubtedly due to the quantity of silt deposited in this hold. Indeed, a low sedimentation rate of 0.1247 Hm^3/year is recorded between 1986 and 2003 due to the fact that the basin underwent a very strong siltation during this period, while the high siltation rate, 0.42 Hm^3 / year, observed between the year 2003 and the year 2006 is due to the small quantities of sediment extracted by devasing of the reservoir on one side and the other, which is possible, due to the quantity of silt arriving at the reservoir basin of the dam. Below the 184 m level, there is an increase in the volume stored compared to that in 1986, this increase is due to stationary dredging and the silt extracted by the six drain valves. Analysis of the topo-bathymetric plans for 2006 shows that the area between the dike and 1200 m upstream is dredged up to the average height of 180 m. At 1200 m, the steep slope shows the limit between the dredged area and the non-dredged area with a slope of 24% (National Dams Agency, 2006). Near the embankment, pits reaching a height of 176 m are due to the stationary dredging carried out in these places. To highlight the influence of curative and preventive actions on the current and future storage capacities of this basin and the quantities of incoming sediment into which, we have drawn the curve, represent the variation over time of the storage capacity, the quantity of sediment extracted, sedimentation in the reservoir and anti-erosion measures implemented and feasible.

Means of fighting against the siltation of the Zardezas dam

The Zardezas dam is among the 20 Algerian dams most threatened by the phenomenon of siltation (Remini, 2017). Several methods of combating this silting up phenomenon have been practiced to reduce solid inputs. Whether at the level of the watershed or at the level of the dam itself.

At the watershed level

Reforestation and development have been carried out in the watershed of the Zardezas dam. The torrential correction was applied in the most advanced gullies (fig. 15). Only given the advanced state of the silting up of the dam, the torrential correction must become generalized over the entire watershed of the dam

Figure 15: Torrential correction by gabions in the watershed of the Zardezas dam, Algeria (Photo Toumi, July 8, 2015)

At the level of the bowl

In view of the scale of the siltation phenomenon, the dike was raised during the period: 1974-1974 to compensate for the capacity lost by the mud deposits. However, over time the silting up phenomenon has accelerated and consequently the loss of storage capacity still persists. This forced the hydraulic services to opt for cleaning up the dam lake using hydraulic dredging (fig. 16). During the period: 1992-2010, a volume of 10.3 million m3 of silt was removed from the reservoir and discharged downstream of the dam. The average rate of dewatering is of the order of 0.67 million m^3/year. The greatest quantities of sediment removed are recorded during the hydrological years 1995/1996, 1998/1999, 2000/2001, 2002/2003 and 2005/2006 (fig. 17).

Figure 16: The dredger used to clear the Zardezas dam, Algeria (Photo Toumi, July 8, 2015)

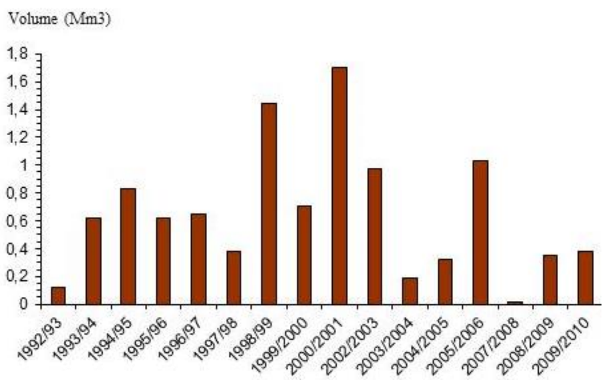


Figure 17: Quantities of sediment extracted from the basin of the Zardezas dam, Algeria (Data of National Dams Agency 2015)

CONCLUSIONS

Can we downgrade the Zardezas dam? Obviously no. Zardezas, a history, a hydraulic heritage, a dam for irrigation, a dam to fight against floods. Silted to more than 65% of its original capacity, the Zardezas dam is threatened more than ever by the rapid filling of the lake. Even the drainage sluices are not immune to successive deposits of mud.

Studies on the settlement and consolidation of the silt must be carried out to locate areas with high sedimentation to facilitate dredging operations. A short-term solution is needed to save the Zardezas. Hydraulic dredging is the only option. Opt for more than three dredges at a time to remove 12 million m^3 of silt in one year. Such an operation must be accompanied by the development of sludge storage basins. The silt settles far from the lake and the water will return to the dam. You have to create a closed cycle. The silt deposited in the storage basins must be used in the fields of construction and agriculture.

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