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DAMS IN THE FACE OF CLIMATE CHANGE!

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ABSTRACT

Dams in the face of climate change is the title of the subject discussed in this article. Based on field work carried out over the last 20 years, it appears that these climate changes have indeed given rise to new behaviors on dams. For the first time in the history of Algerian hydrotechnical infrastructure, the water in the dam is drying up and all activities around the dam are stopping. Very harsh as a consequence ; this new parameter (drying up of the lake) is slowing down the development of aquaculture and therefore it is impossible to promote sustainable fishing in this area (dam) especially for small and medium dams. The dam can also fill up completely during a single flood. This can cause a landslide or pose a problem of stability of the structure. After a long drought of 6 to 7 months, torrential floods bring significant quantities of water to the dam but which are loaded with fine particles. Such a phenomenon causes the appearance of density currents which propagate below the clear water of the lake depositing sediments at the bottom of the dam. In both seasons (dry and wet), the dam loses a volume of water by evaporation and siltation. The dam must continue to play its role of storing flood waters and reusing them in periods of drought, but modifications to the structure must be made so that the dam adapts as well as possible to the new climate.

Keywords: Dam, Climate change, Lake drying, Rapid lake filling, Rapid siltation, Density current.

INTRODUCTION

The reservoir dam, a very old technique used to store surface water during the wet season to reuse it during the dry period. Their role differs from one dam to another, it can be intended for irrigation as it can be intended for the supply of drinking water. However, these dams encounter certain natural problems, particularly those located in arid regions. In this case, the filling of the reservoir is carried out during flood periods and the useful volume is always threatened with occupation by the advancement of the dead volume following the accelerated deposits of sediments at the bottom of the reservoir. Today, climate change causes the disruption of two parameters: rainfall and temperature, which are directly linked to the operation of the dam and therefore to the satisfaction of demands for drinking water or irrigation water. This means that the threshold of the useful volume of a dam must be invariable over time for the dam to be able to adequately satisfy its demand for water. However, it turns out that the two climatic parameters: temperature and rainfall are currently undergoing extreme variations. The significant increase in temperature and the significant decrease in rainfall are shaping today's new climate with a long drought followed by a short wet period characterized by torrential rains and sudden and devastating floods. In this new situation, the dam is impacted by the disturbances of this new climate. It turns out that its useful volume risks a decrease and sometimes even a total drying out by evaporation or a filling of the dam itself by siltation. Extremely serious cases have occurred in recent years in the world and in Algeria. During the year 2024, the Bakhadda dam lake with a volume of 50 million m^3 which supplies the wilaya of Tiaret was completely exhausted following a long drought. The Boukourdane dam with a capacity of 104 million m^3 the useful volume of the dam has been dried up and today the dam only exploits the dead volume, obviously by using a floating pumping system. The Foum El Gherza and Fontaine des Gazelles dams, which are intended for the irrigation of the palm groves of Sidi Okba and the irrigation of the Loutaya plain, suffered a "temporary death" until the last floods of August 2024. Whether they are the dams of North Africa or those of the Mediterranean basin, these dams are today in an extremely delicate situation. How will they respond to an overly demanding demand for water, whether to satisfy the thirst of the population or to satisfy the quantity of water intended for irrigation, which is increasingly high. This paper, in at first approach, discusses the new situations of dams in Algeria that are created by this sick climate.

ALGERIAN DAMS AND FIELD OBSERVATIONS

Surface water storage dam, a technique invented several centuries ago and it is practiced in all countries of the planet just like traditional wells. In Algeria, the dam has been built in the wadis for many centuries. The first water storage dams were made of gypsum, but they are filled with spring water. Equipped with two frontal seguias, this type of dam is intended for the continuous irrigation of gardens located below the structure itself (Figs. 1 and 2). Originally, it is impossible to determine the number and year of construction of this type of hydro-agricultural structure. However, according to our study, these dams are located mainly in the regions of Ziban, Aurès, the oases of El Bayadh, the oases of Naama and the oases of Saoura. Due to repeated droughts in these regions caused by climate change, the lowering of water tables has caused the depletion of water sources and consequently the drying up of these dams.

Figure 1: Tiout Dam, among the first dams built in Algeria (more than 7 centuries) (Photo. Remini, 2006)

Figure 2: Hydro-agricultural dam located in the Ziban region intended for the irrigation of oases among the first dams built in Algeria (Photo. Remini, 2018)

According to two studies carried out by the author himself on Algerian dams, a generation of dams was built during the colonial era consisting of about 20 dams from the year 1860. Only a few dams were decommissioned following total filling like the dams. Others were washed away by floods like that of Fergoug 1 in 1870. Thirteen dams have resisted the various droughts and are currently in operation like the dams of: Meurad, Hamiz, Ghrib, Oued El Fodda, Zardezas, Ksob, Foum El Gherza, Foum El Gueiss, Mefrouch and Beni Bahdel and Bouhanifia. Boughezoul and Fergoug. The third generation of dams was built after Independence and contains 71 dams in operation today. However, in the early 1980s, the Algerian government's water strategy was based on the multiplication of dams throughout the northern part of Algeria. In 2024, Algeria has 81 dams in operation with a total capacity of 8.5 billion m^3. It is interesting to note that from the year 2000, following a long drought, the Keddara dam suffered a temporary death since its useful volume was completely dried up. It was from the year 2000 that the Algerian government opted for the desalination of seawater by building large plants. This strategic choice somewhat abandoned the dam policy and thus the rate of dam construction decreased in favor of the construction of desalination plants. Only after 20 years, in 2020, the drought returned again with force, causing several dams to dry up due to high evaporation, including those of Boukourdane, Foum El Gherza, Djorf Torba and even that of Keddara. Other dams have seen their capacity completely deprived thanks to accelerated siltation such as those of Fergoug, Foum El Gueiss, Zardezas and Foum El Gherza. This has pushed the current government to accelerate the construction of several seawater desalination plants in northern Algeria and brackish water in southern Algeria. So to alleviate the thirst of the population, the choice was made on seawater to the detriment of surface water.

RESULTS AND DISCUSSIONS

The climate is no longer the same as before. Disruption, global warming or climate change, the result is the same; water is becoming increasingly scarce. A variation in the two climatic parameters: rainfall and temperature are enough to cause a climate disaster. Composed of four seasons, the hydrological year that we have known in the past has been converted into a long season of drought followed by a short period of floods and floods. It is this new climate that is being established in the regions of North Africa and the Mediterranean basin. The first victim of the sick climate is undoubtedly the water resource. More particularly, it is surface water that is threatened by the exhaustion and drying up of storage reservoirs. In return, the precipitation water that has infiltrated into the subsoil is stored in natural reservoirs called aquifers. These groundwaters are hidden away from siltation and evaporation. We can say that groundwater is the water that can withstand climate change. In other words, countries that have more aquifers are protected from climatic hazards. As for surface waters that run off and flow into rivers, they are visible waters and are generally the best studied. Conversely, groundwater is invisible water and therefore, it is complex and poorly studied. Generally, in large quantities, surface waters are much more stored in natural reservoirs (lakes) and artificial reservoirs (dams). As you know, dams remain the oldest hydraulic development on the planet, which consists of storing rainwater during wet periods to reuse it during periods of drought. However, today in the era of climate change and in recent years, the phenomenon of dam water drying up has become a common occurrence (Fig. 3).

Figure 3: Mefrouch Dam, Drying of the dam lake following the phenomenon of evaporation; Image that will be repeated in the coming years (Photo from Habi, 2006)

Since the long drought that affected Algeria in the early 2000s, this new situation has become commonplace since several dams have been seen to be dry, starting with the reservoir of the Keddara dam which was exhausted during the drought of 2000. It should be noted that the Keddara dam plays an important role in the drinking water supply of greater Algiers. With a capacity of 143 million m^3, the Keddara dam is the real water tower of greater Algiers. This particular hydraulic development was carried out to fill the absence of a favorable site to build a dam with a capacity of 143 million m^3 near Algiers. A dam of such a capacity on the Keddara wadi is automatically an oversized dam, since the Keddara River carries a low flow of water. The construction of the Keddara dam is carried out on this wadi to simply play the role of a water tower located 30 km away that supplies greater Algiers. This water tower is filled by 3 ways: the first part of water comes from the Keddara River. The second quantity of water comes by gravity from the Hamiz dam. The third quantity of water comes from the Beni Amrane dam. The latter was built on the Isser wadi and constitutes the lung of the Keddara dam since it contributes to the filling of the Keddara reservoir by the pumping station at a rate of 7 m^3/s. However, it is interesting to emphasize the solid transport in the Isser wadi is very important and poses siltation problems at the Beni Amrane dam (Larfi and Remini, 2006). This project is part of the Greater Algiers drinking water supply called IKPS (Isser Keddara Production System). Commissioned in 1987, the IKPS project remains one of the best hydraulic developments in Algeria. It so happens that in the early 2000s a long drought hit Algeria. The first victim of this sick climate is undoubtedly the drawdown of the Mitidja water table and the drying up of the Keddara dam lake (Fig. 4). This is only the result of low liquid inputs from the Isser wadi and the lowering of the water level of the Hamiz dam.

Greater Algiers was forced to supply itself with the "dead" volume of the Keddara dam using a floating pumping station.

Figure 4: Keddara Dam, the water tower of Greater Algiers during the 1980s and 1990s, suffered two water shortages during the period 2000-2024 (Photo from Remini, 2024).

Such a situation has created an unprecedented water crisis. This has prompted the authorities to build seawater desalination plants to fill the deficit in surface and groundwater. Over the past 20 years, around ten dams have seen their waters run out due to repeated droughts. In 2020, the drought returned in force and caused the same scenario as that of the early 2000s, namely the drying up of the dam lakes. Several examples have been reported on the national territory, namely the Bakhadda dam, which caused an unprecedented crisis in the cities of the wilaya of Tiaret due to the exhaustion of the useful capacity and the silting up of the dead volume of the dam. The useful volume of the Boukourdane dam has been completely consumed. However, the dam continues to meet its demand for drinking water by exploiting the waters of the dead volume, since the latter is classified among the least silted dams in Algeria (Fig. 5).

Figure 5: Boukourdane Dam in a critical situation. Due to a low siltation rate, the dam exploits the waters of the dead volume to satisfy its demand for drinking water (Photo from Remini, 2024).

Victims of climate change, the reservoirs are exhausted and the use of invisible waters becomes an essential step. Such a situation has created unprecedented pressure on the exploitation of aquifers, which has led to an accelerated drawdown of the water tables. To remedy the water deficit, other seawater desalination plants have been built. So what we have seen during these two long droughts is that surface water is the first victim of climate change. As we mentioned at the beginning of this paper, two parameters have contributed to the decrease in the volume of water in the dams. These are evaporation and siltation. The first occurs in dry periods following high temperatures. The second parameter occurs in wet periods. This period records flash floods that cause intense erosion and consequently significant silty deposits at the bottom of the dams. This new situation caused by the phenomenon of climate change requires a review of the construction and management of dams, especially in the regions of North Africa and the Mediterranean basin. Despite this new climate, dams must continue to play their role, which is to store surface water, except that today dams are filled with flood water. But this time the floods are much faster and more aggressive; we are talking about flash floods. These new floods bring back significant quantities of water that are supposed to fall in 12 months, but they fall between 36 hours and 48 hours. In addition, these water inflows drain considerable masses of mud. The contact of the loaded waters with the clear waters of the lake of a dam causes the birth of density currents that propagate below the clear water in the form of a concentrated, well-individualized liquid beam. These turbidity currents will multiply with the new floods. In addition, torrential rains that fall on dissected and crumbled soil following a dry tongue cause rapid runoff that creates new ravines that become more pronounced depending on the duration and intensity of the rain (Fig. 6).

Figure 6: New gullies that form with each new flash flood. The intense runoff creates more and more gullies (Photo from Remini, 2019a)

The repetition of this runoff phenomenon after each long season causes the appearance of new ravines and the deepening of old ravines in a first stage. In a second stage, it is around the widening of the section of the ravine. In the last stage, it is the stage of very advanced degradation of the ravine, or human intervention will have no effect on the recovery of such an agricultural space (Fig. 7).

Figure 7: A view of part of the Beni Chougrane watershed showing very advanced gullies. Such an image will be repeated in other basins in the years to come (Photo from Remini, 2017)

In this transition phase, flash floods are resizing the sections of wadis and tributaries. This new situation allows these rivers to carry significant quantities of water (Remini, 2023). These are torrential rains that fall only in 48 hours and are supposed to fall throughout the year. These flood waters are blackish or yellowish in color due to a high concentration of fine particles. This generates a high driving force that allows the density current to propagate quickly and easily reach the foot of the dam and consequently the silting of the dams accelerates (Remini, 2019b) (fig. 8). In this case, several dams will be threatened by successive deposits of silt at the bottom of the reservoirs (Remini and Hallouche, 2004. Remini, 2017).

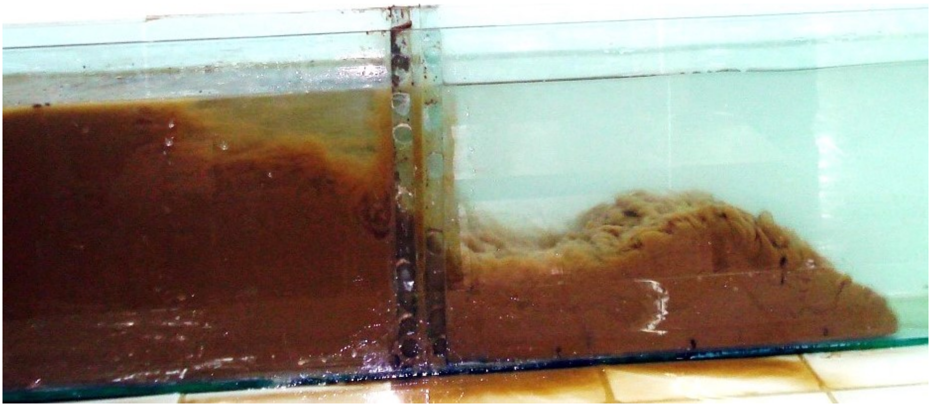
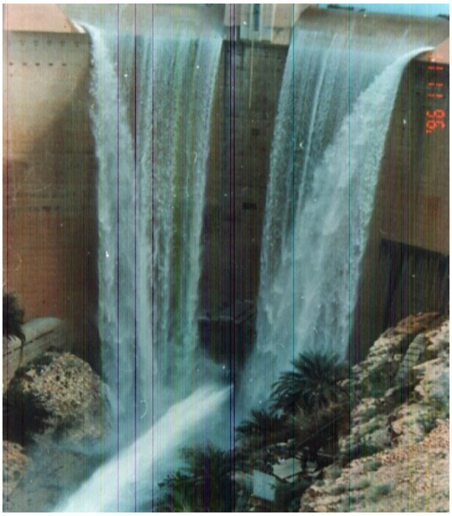


Figure 8: Density current or turbidity current, a phenomenon that will be repeated more and more with the increase in flash floods. Be careful, the dams will silt up much faster than before (Photo from Remini).

However, it is interesting to note that these sediments landed at the bottom of the dam lake are a direct consequence of water erosion that occurs in the watershed. With this new climate characterized by a long dry season that lasts from 4 to 6 months, it is characterized by high temperatures exceeding 45°C and can even cause huge forest fires. This new situation has produced two phenomena: erosion and evaporation, which have the direct consequence of reducing the useful volume of the dams. During these long dry spells, the particles of the upper layer of the soil easily detach and crumble (fig. 6). The arrival of the winter season with these torrential rains that fall on fragile and degraded soil triggers the erosion phenomenon. What can be said is that repeated droughts accelerate the erosion phenomenon and consequently quantities of mud are deposited more and more in the dams. In addition, erosion causes the loss of nutrients and the degradation of soil structure, and consequently soil productivity declines more and more. Regarding the evaporation of lakes (natural and artificial), this phenomenon, which occurs during the dry season that can last 6 months or more, causes the transfer of a significant amount of water (in gaseous form) to the atmosphere. In recent years, evaporation from dam lakes has reached values of 2 to 2.5 meters in height per year in northern Algeria. A study carried out in the early 2000s on 39 dams in operation in Algeria showed that a loss of water through evaporation reached the threshold of 250 million m3/year (Remini, 2005; Remini, 2010). In Lake

Chad, the average annual evaporation is around 4 to 5 m (Bouchardeau in Remenieras, 1986). In Chott El Djerid, evaporation reached 2858 mm (Mamou, 1990). What must be remembered is that the management of a dam today has become much more complex than before. The manager of a dam must manage a double reduction in the capacity of the dam. The first decrease is invisible which corresponds to evaporation. The second decrease corresponds to a visible decrease which corresponds to the successive deposits of sediments at the bottom of the dam. Regarding the phenomenon of evaporation, the long duration of the drought causes evaporation and late filling of the dam. This leads to a rapid depletion of the useful volume of the dam. The exploitation of the "dead" volume of the dam becomes in this case a necessity. Obviously, the drawing of this volume of water requires a floating pumping station. This image of a dry dam has become a common image over the last 20 years since around ten dams have seen their water dry up. We can cite a few examples of dams. These are the Keddara (2000), Boukourdane (2022), Tlemcen, Foum El Gherza (2023), Fontaine des Gazelles (2023) and Annaba dams. The dams that are threatened by the drying up of their reservoirs are small dams and silted dams (Fergoug). Unlike large dams that will be spared by this phenomenon because of their volume that can withstand the duration of the drought. The Beni Haroun dam with a capacity of 1 billion m3 has resisted all the episodes of drought that have occurred in recent years since the distribution of its water has not been disrupted in recent years and has been operated in a continuous way to supply as usual 5 wilayas of eastern Algeria. With this new climate, it is necessary to avoid developing aquaculture in the lakes of low-capacity dams, due to the lack of rapid drying of the reservoir. On the other hand, in all large-capacity dams, aquaculture can develop normally. Managers of low-capacity dams can take advantage of the dry period when the dam is dry to organize mechanical dredging operations of the mud. However, the mud should be discharged into the wadi downstream of the dam provided that this wadi flows directly into the sea. Except that these tons of mud that have been deposited for years at the bottom of the dams and that today this quantity of mud will be carried away by one for two successive floods towards the sea. Therefore, mechanical dredging can be carried out preferably for small and medium-sized dams located on wadis that flow towards the sea. The mud removed from the reservoir must be discharged into the wadi downstream of the dike. The first liquid inputs to the dams must be evacuated through the drainage sluices which will create artificial floods and sweep away the sediments deposited on the bottom of the reservoir and most importantly drain and push the mud deposited on the wadi bed towards the mouth. Another method is to reduce the mud in a reservoir of a low capacity dam. During the drying up of the lake of a dam, tractors can plow the soil at the bottom of the reservoir. It is the mud consolidated for several years following the successive deposits of mud that has been plowed. The bottom valves open, the first artificial floods after a long drought will drain the plowed land and evacuate it through the drainage sluices. Therefore, we can say that during the drought period the operation of cleaning the dried dams becomes mandatory. Under the effect of climate change, reservoir dams record a significant water deficit during the long drought period. However, during the short flood period, the dams will be supplied with excessive quantities of water in a short period of time. In this case, this image will be repeated several times in the years to come. Already, in recent years, the Beni Haroun dam spillway has discharged excess water practically during each flood.

Therefore, under the effect of climate change, the transition from the dry season to the wet season causes a rapid rise in the level of the dam lake, going from one extreme to the other, i.e. from a zero level which corresponds to the useful volume equal to zero to a normal level which corresponds to the normal volume of the reservoir; i.e. the level of the spillway discharge. These two extremes can be observed during the same hydrological year (Figs. 9 a and b).



a)

b)

Figure 9: Foum El Gherza Dam. Both extremes (empty and full) can be observed during the same hydrological year in any dam. a) During flood period (Photo from ANBT, 1996); b) During drought period (Photo from Remini, 2024)

The frequency of occurrence of this phenomenon is shortening in the coming years, especially for small dams and silted dams that have a useful capacity reduced by silt deposits. In addition, reservoir dams can record exceptional floods, which have never been recorded in the archives. In this case, the dam's flood spillway is undersized compared to these new floods and consequently the water overflows the dam which behaves like a rectangular spillway despite the opening of the drainage sluices. The case of the Foum El Gherza dam (Biskra) is a good educational and scientific example that we must take seriously. It was during the flood of November 2011 with an estimated flow of 1600 m3/s that was drained by the Labiod River. Despite the operation of the spillway and the opening of the bottom valve, the flood of an estimated 6 m of water passed easily over the crest. Fortunately, the arch-type dam did not have any stability problems. In 2011, the dam was silted up to more than 70% of its initial capacity. This situation greatly helped the flood to flow easily over the dike. The same problem occurred in 2023 in Libya and more precisely in the municipality of Derna. Due to heavy rainfall that lasted only 72 hours to see a huge flood equivalent to 12 months of rainfall that fell in 36 hours. Such a mass of water is far greater than the dam's evacuation capacity. Built with rockfill, the

Derna dam cannot withstand such a deluge. The water passed over the dike and washed away any obstacle on its route. Such a phenomenon may be repeated in the short or medium term. As we mentioned previously, the Labiod wadi has already recorded an exceptional flood that passed over the dam of the Foum El Gherza arch dam. A 6 nm sheet of water above the crest of the dam was observed despite the opening of the bottom valve to weaken a little the rapid rise in the water level of the dam lake. It only takes a time of 80 hours during the period from October 28 to 31, 2011 to obtain a flood with a flow of 1600 m3/s. Fortunately, no material damage or human losses were recorded. Today, to strengthen the safety of the Foum El Gherza dam, a spillway dam has been built just at the exit of the narrowing (Mchounech canyons). This place is the most dangerous of the Labiod wadi with a length of more than 100 km. The water comes out with an impressive speed and causes damage in the section that passes through the oasis of Mchounech. The Mechounech bridge was washed away by the flood of 2011, which shows the aggressiveness of the flood.

CONCLUSION

As we mentioned at the beginning of this paper, dams are a technique that has lived for several long centuries to store surface water during rainy periods to reuse them during droughts. Only today with droughts of long periods of 6 to 7 months, dams can no longer meet the demand for irrigation water or drinking water. A terrible pressure has been exerted on dams whether to alleviate the thirst of the population or to irrigate agricultural land because of the demand for water that continues to increase more and more. Even with the arrival of the short wet season which is characterized by devastating flash floods draining large quantities. However, these flash floods carry several tons of mud that settle at the bottom of the dams. The waters of these waters are too loaded with clay particles thus giving a yellowish or blackish color. At the entrance to the dam lake, billions of particles will gather in the form of a viscous clay layer; the latter flows on the bottom of the dam to reach the foot of the dam to finally deposit these tons of sediment at the bottom of the dam. This new climate must be taken into consideration by the dam services for good management of the Algerian hydrotechnical infrastructure. Should we continue to develop aquaculture in low or medium capacity dams with a drought duration that can reach 7 months ? Should we continue to build hill reservoirs which are threatened by evaporation, siltation and the magnitude of the flood itself ? Be careful, a dam is dry for several months and suddenly thanks to a single flood it fills completely. This poses a problem of landslide and consequently the stability of the structure itself comes into play.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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