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D – data interpretation
E – manuscript preparation
F – literature search

Surface water leakage, sedimentation and evaporation in arid regions: A case study of the Gargar dam, Algeria

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Abstract

This study was carried out in order to assess the total capacity loss in Gargar dam, third-largest in Algeria, due to the mudding of the reservoir, intense evaporation and water leaks. We analysed the variation in leakage as a function of the reservoir level, and quantify losses due to leaks, sedimentation and evaporation. We relied on site visits and data obtained from the Algerian Agency for Dams and Transfers to assess the leakage volume; reservoir level; sedimentation and evaporation levels for the period 1988–2015. We present an updated report of this problem through the dam. We estimated total average losses of 23 million $m^3 \cdot year^{-1}$ for the period 1988–2015, made up of leakage (0.3 million $m^3 \cdot year^{-1}$), evaporation (18 million $m^3 \cdot year^{-1}$) and dead storage for 4.6 million $m^3 \cdot year^{-1}$. However, total losses for 2004 were estimated at 113.9 million m^3, which increased to the alarming value of 166.8 million m^3 in 2015. We suggest improving the waterproofness by a concrete screen, and reducing mudding and evaporation by reforestation, to increase the storage capacity of the dam.

Key words: *arid zones, evaporation, Gargar dam, leakage, sedimentation*

INTRODUCTION

Annual average rainfall in Algeria is estimated at 100 billion m^3. Of this, 80 billion m^3 evaporates, 5 billion m^3 is lost to surface runoff, 3 billion m^3 seeps into the ground [ANBT 2015], while most of the remainder ($73 \cdot 10^9$ m^3) pours directly into the sea. Currently, the country has more than 50 operational dams, with a capacity of 5 billion m^3, providing an annual volume of 20 billion m^3 of water for human consumption, industry and irrigation. Not only has drought afflicted the country for the past twenty years, but also reservoirs are subject to intense evaporation, high levels of sedimentation and leakage. Most Algerian dams have a lifespan of about thirty years. However, it is rare to abandon a dam so soon, especially when the reservoir holds water intended for human consumption or irrigation. Reservoirs and lakes in arid areas are particularly exposed to evaporation due to high air temperatures (especially in the dry season), hot sun (all year) and strong, dry winds (especially in the autumn and spring), which leads to very high annual losses. For example, annual average losses for the Bouhanifia dam (which has never reached its maximal capacity) are estimated at 50 $m^3 \cdot year^{-1}$ for the period 1940–2016. In turn, annual losses due to sedimentation are estimated at 50 million $m^3 \cdot year^{-1}$ for the period 1986–2015 and losses due to leakage were estimated at more 40 million $m^3 \cdot year^{-1}$ for the period 1986–2015. Certain dams are particularly affected: average annual leakage from the Foum el Gherza dam is estimated at 5 million $m^3 \cdot year^{-1}$ and 11 million $m^3 \cdot year^{-1}$ from the Ouizert dam, where record losses of 23.34 million m^3 were recorded for the year 1995–1996. The smaller Foum el Gherza dam (capacity 47 million m^3). Commissioned in 1950, it is fed by the El Abiod River. Its location, on Maestrichian limestone results in leakage of up to 5 million $m^3 \cdot year^{-1}$. However, here it is likely that sedimentation has helped to slow losses over time. Another example is the Hammam Grouz dam, where average leakage is around 50,000 $m^3 \cdot day^{-1}$ (i.e., ten times higher than the Foum El Gherza). This is mainly due to high levels of erosion (heavy rain, lack of vegetation, Bare relief geologically young, etc.). Leakage leads to considerable losses of valuable, scarce water. It also presents a serious threat to the stability of hydraulic structures and exacerbates the problems of sedimentation and evaporation [ANBT 2015; REMINI, AVENARD 2003]. Leakage has evolved over time. While most dams in Algeria are threatened by the phenomenon, it particularly affects those that are situated in arid and semi-arid areas where economic development is closely linked to the availability of water. Our work has estimated total average losses of 25 million $m^3 \cdot year^{-1}$ for the period 1988–2015. However, total losses in 2004 were estimated to be about 113.9 million m^3, which increased to the alarming value of 166.8 million m^3 in 2015. Earlier work has analyzed this variation as a function of losses due to leakage, sedimentation and evaporation [SGSLHW 2015]. The Algerian National Agency for Dams and Transfers (Fr. Agence Nationale des Barrages et Transferts – ANBT) currently takes daily measurements of evaporation from 39 major dams with a total capacity of 3.8 billion m^3. Maximum evaporation (350 million m^3) was recorded in 1992–1993 and the minimum (100 million m^3) in 2001–2002. The annual average over the period 1992–2002 was 250 million m^3 (6.5% of total capacity). These data highlight a clear evaporation gradient: in the coastal zone (up to 50 km from the sea) annual evaporation is <0.5 $m^3 \cdot year^{-1}$, compared with a band 50–150 km from the coast, where it is 0.5–1 $m^3 \cdot year^{-1}$. In some cases, leakage is so substantial that a collection system has been put in place to recover water lost downstream and direct it to farmland. In recent years, the total volume lost ranges from 20–75 million m^3. However, until now, no detailed analysis has been performed of the Agency's data.

Fifty-seven major dams currently operate in coastal and central areas, while only eight are in the (arid) south. The Djorf Torba dam in southwest Algeria, illustrates the problem of evaporation. Commissioned in 1963, the dam has a capacity of 350 million m^3. Between 1992 and 2002, losses due to evaporation exceeded the quantity needed for the supply of drinking water and irrigation. They reached 90 million m^3 in 1994, which represented approximately twice the total volume required for consumption. Maximum losses of 18 million m^3 were recorded in 1994–1995. Since then, increasing losses have been explained by sedimentation [ANBT 2015; REMINI 2015]. The abundance of carbonate series and karst topography throughout Northern Maghreb suggest that there is a high risk of the loss of surface water in wadi beds such as reservoirs. Although in some cases (notably the dams of Djorf Torba and Foum el Gherza), fine cracks can close over time, the phenomenon is not systematic: when the karst network consists of large conduits, sedimentation does not have a significant impact on the surface–subsurface exchange. This is the case for the Ouizert dam (in Algeria) and the El Haouareb Merguellil dam (in Tunisia), where sedimentation has reduced losses due to leakage [ANBT 2015; COYNE 1994; ROYET 2006]. In Algeria, we have identified 25 dams where losses exceed 1 million $m^3 \cdot year^{-1}$. In six cases, leakage exceeds 5 million $m^3 \cdot year^{-1}$, notably including the Gargar dam (subject of our study). This dam is extremely susceptible to leakage and a gradual reduction in its storage capacity has been observed over time. In this study, we examine the reasons and analyse the variation in losses due to leakages, sedimentation and evaporation [ANBT 2015; REMINI 2003].

DATA AND METHODS

LOCATION AND CHARACTERISTIC OF THE GARGAR DAM

With a capacity of 450 million m^3, the Gargar dam is the third-largest in Algeria, after Beni Haroun (998 million m^3) and Koudiat Acerdoune (650 million m^3). It is located in the region of Relizane, 5 km Southwest to the village of Oued Rhiou, and 3 km upstream from the bridge on the Rhiou River (which is a tributary to the Chellif River) in the Cheliff Zahrez watershed where dams are most exposed to sedimentation. The study zone covers an area of 2,900 km^2. It belongs to the Rhiou river watershed. A gorge, carved into the crest of the limestone hills along the Southern edge of the plain of Chellif, forms the dam site. Made of clay, the dam created a large reservoir designed to contain the highly-seasonal flow of the Rhiou River, with annual average inflow of 185 hm^3 (Fig. 1) [ANBT 2015].

The first study campaign for the construction of the dam was conducted in 1926, and was followed by further studies in 1929, 1932 and 1967. Three other sites were examined, before an embankment dam was finally built in the area of the gorge of Gargar, exploiting the geotechnical soil conditions and available materials. Construction works began in June 1984, and ended in October 1988, while the reservoir was filled in November 1988. All works were finished in September 1990 [ANBT 2015; ATKINS 1982]. The dam supplies water for the irrigation of 16,000 hectares in the Lower Cheliff plains and supplies drinking water to the large city of Oran and 15 other towns and villages in Relizane and Mostaganem provinces. According to the National Water Plan, the Lower Cheliff irrigation perimeter is 50 $hm^3 \cdot year^{-1}$. During the period 1992–2004, when water was supplied to the city of Oran, the reservoir's volume dropped by an average of 30.36 $hm^3 \cdot year^{-1}$. Other towns and villages

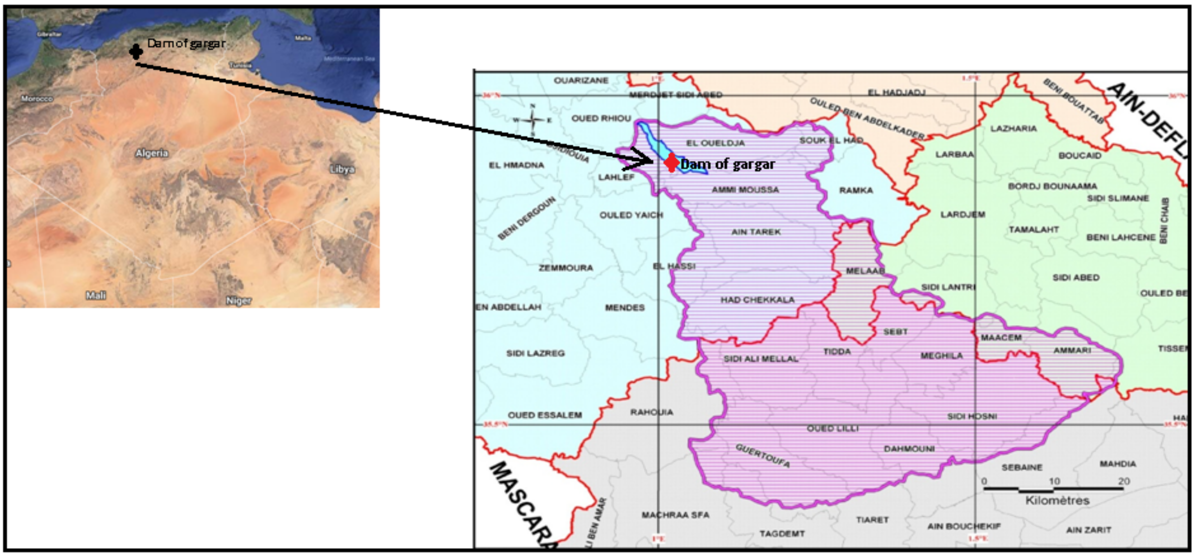

Fig. 1. Location of the Gargar dam; source : own elaboration

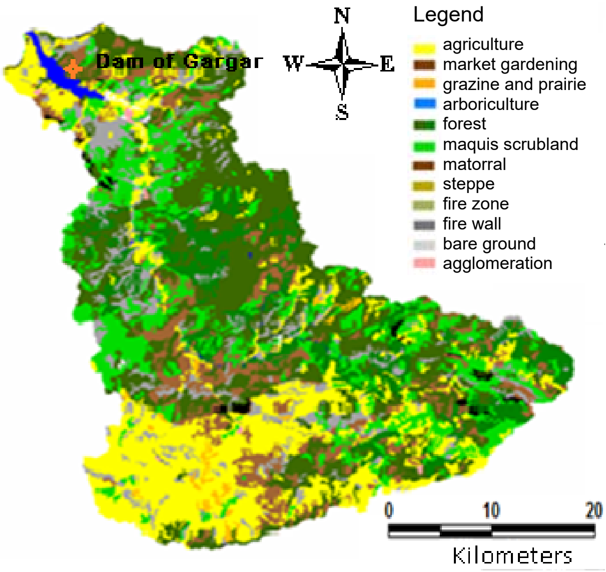

Fig. 2. Vegetation cover; source: own elaboration

in the area (population 33,763 in 2003) were expected to require about 5 $hm^3 \cdot year^{-1}$. However, water supply to the area for the period July–August 2003 was about 9.64 hm^3. It is predicted that in the near future, nine locations in Relizane province will require 400 $dm^3 \cdot s^{-1}$ (13 $hm^3 \cdot year^{-1}$). At the same time, a water treatment plant is scheduled to come online [ANBT 2015; REMINI 2003].

The climate in the watershed has two features. The upper basin is characterized by a rainy mountainous climate, with cold to relatively low temperatures and heavy snow. The lower basin is characterized by a relatively warm, dry climate with high temperature variation. Average monthly temperature in 2006 ranged from 8.40–39.84°C with an annual average of 18.2°C. Rainfall and hydrometric data were used to reconstruct a continuous series over a 19-year period (1990–2008), which found an annual average of 72.58 $hm^3 \cdot year^{-1}$. For the period 1984–2008, sedimentation was estimated at 4.5 hm^3 with an annual percentage of about 2.5% of initial capacity [ANBT 2015; SGSLHW 2015]. The dam's lifespan has been estimated at about 150 years. Vegetation includes *Olea*, *Quercus ilex* and *Pinus halepensis*. *Thuja* dominates to the west of the Rhiou River, but this highly-resistant genus is subject to ongoing degradation due to human actions and forest fires (Fig. 2) [ANBT 2015; ATKINS 1982; SGSLHW 2015].

GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT

At the dam site, the Rhiou river has cut a gorge into the limestone cliffs of the Gargar and Abbadia Djebels. This topography means that there has been longstanding interest in constructing a dam. Upstream, the valley expands around the village of El Alef to form a natural basin that is largely covered by limestone [ATKINS 1982]. The Tortonian marl is covered by a discontinuous limestone ridge of the same age. The river bed contains thick deposits of recent alluvium consisting of sand, gravel and pebbles, together with silt and clay. Excavation of the dam site found that the alluvium extends to −115 m, −42 m at the coast and −38 m along the axis of the dam's river channel. There is evidence of large variations in the river level in the geological past. Karst features, although small, are frequently found on both the right and left banks of the river. Excavation of the spillway found funnel structures and underground channels filled with silt or clay as a result of dissolution. The upper area of the dam has extensive recent terraces of clay and silt. The mountainous slopes and ridges overlooking the gorge are smooth, showing that they were levelled by sediment transport when the sea level was much higher than the present day [ANBT 2015; ATKINS 1982; THEROND 1980]. Lugeon tests carried out before the start of the project showed a mean (range) permeability of 2 (1–15) Lugeon close to the surface and 10 (1–15) Lugeon at depth. During implementation of the project and the injection of water, the mean (range) permeability down to the marl clay (passing through the limestone, sandy marl and conglomerate) was 51 (1–580) Lugeon. Tests carried out on the marl clay after clearing the river bed of alluvium gave a mean permeability of about 1 Lugeon, which led to a decision not to inject any water [ANBT 2015; ATKINS 1982; THEROND 1980].

The reservoir basin is mostly composed of relatively impermeable marls, which form a natural curtain that prevents percolation losses. Limestone outcrops are found over a considerable distance on both sides of the dam's supports. Many Lugeon limestone tests were carried out, and all found low numbers (maximum 15) despite fractures, faults and micro karst features in some areas. This impermeability and the length of flow paths suggest low seepage losses [ANBT 2015]. Although the groundwater level is lower, it barely rises above the level of the river. A certain volume of water was absorbed into the soil during the establishment of the new groundwater regime. While there are no geologic structures that could cause large-scale leaks, several minor karst features characterized by secondary porosity are observed, which are probably close to vertical cracks. It was therefore considered prudent to extend the grout curtain to approximately 150 m on each wing to help to locate any other karst areas that could potentially cause leakage. The grout curtain was continuous in order to limit permeability to below 5 Lugeon. The risk of leakage through the karst is also present in areas below the dam's wings. However, early surveys suggested that the extension of the injection program to more than 150 m beyond the dam was unwarranted, unless exceptional features appeared during the injection. It was thought that if percolation areas subsequently developed along pathways in downstream areas, additional injections could be needed (Fig. 3) [ANBT 2015; ATKINS 1982; THEROND 1980].

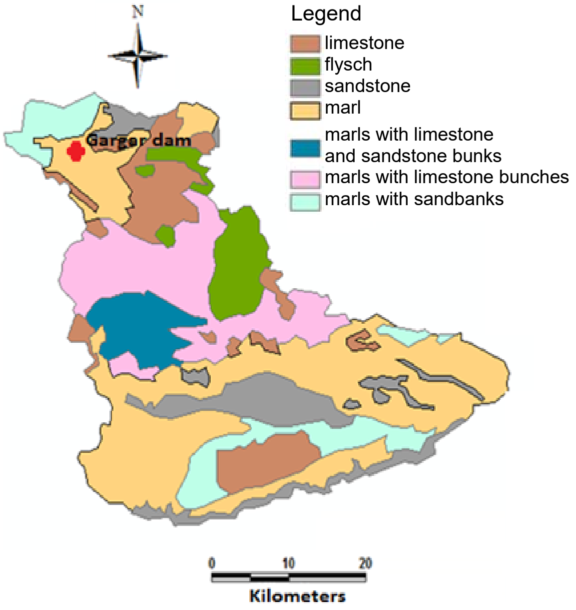

Fig. 3. Geology of the site of Gargar dam; source: own elaboration

DATA INCLUDED

Leakage volume, reservoir level, sedimentation and evaporation levels data were provided by the ANBT for the period 1988–2015. The study consisted of two parts: (1) the analysis of hydraulic problems (leakage, evaporation, sedimentation), and (2) the quantification of losses [ANBT 1988–2015a; BENFETTA, REMINI 2015].

RESULTS AND DISCUSSION

LOSSSES DUE TO LEAKAGE

The first analysis concerned the volume of leakage through a study of variations overtime and as a function of the reservoir level. Figure 4 shows leakage estimated by the ANBT for the period 1994–2015 and highlights significant variation. Average annual loss is 0.3 $hm^3 \cdot year^{-1}$. The problem is ongoing, and changes from one year to another. Figure 5 shows variation in leakage as a function of the reservoir level, and highlights the close correlation (R^2 = 0.98). The second part of the study analyzed leakage flow rates ($dm^3 \cdot s^{-1}$) for 2004–2008 (Figs. 6–7) and as a function of the reservoir level (Fig. 8). Figure 6

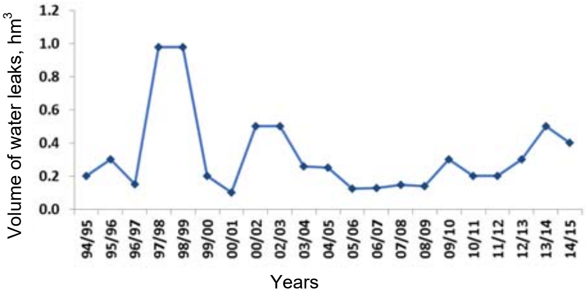

Fig. 4. Leakage (hm^3) in 1994–2015; source: own study

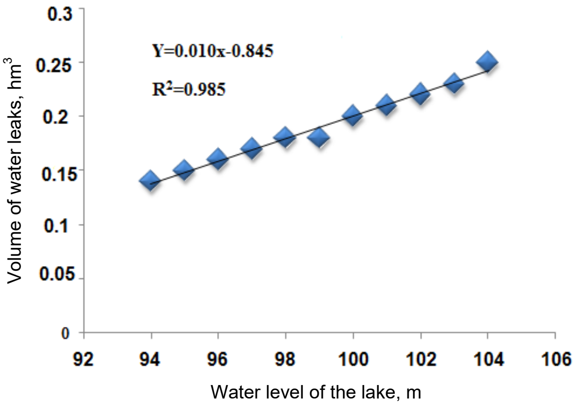

Fig. 5. Leakage (hm^3) as a function of the reservoir level (m); source: own study

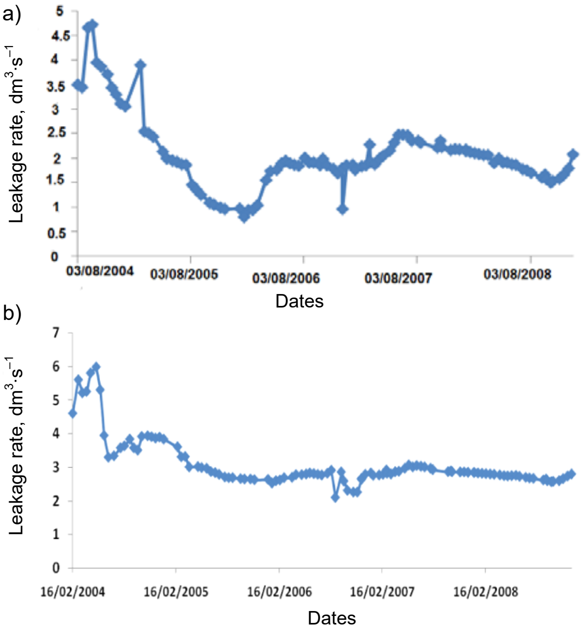

Fig. 6. Leakage flow rate ($dm^3 \cdot s^{-1}$) in 2004–2008: a) from left bank, b) from right bank; source: own study

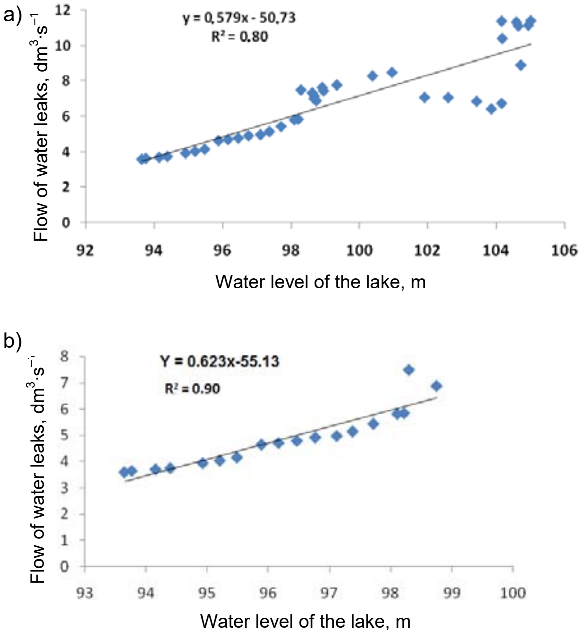

Fig. 9. Leakage ($dm^3 \cdot s^{-1}$) as a function of reservoir level (m): a) in 2004–2005, b) in 2005–2006; source: own study

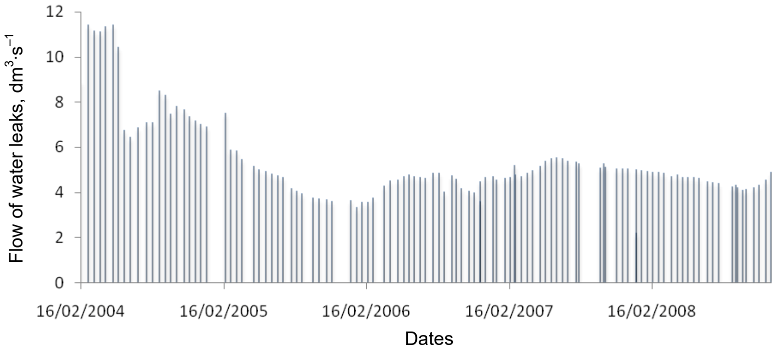

Fig. 7. Total leakage flow rate ($dm^3 \cdot s^{-1}$) in 2004–2008; source: own study

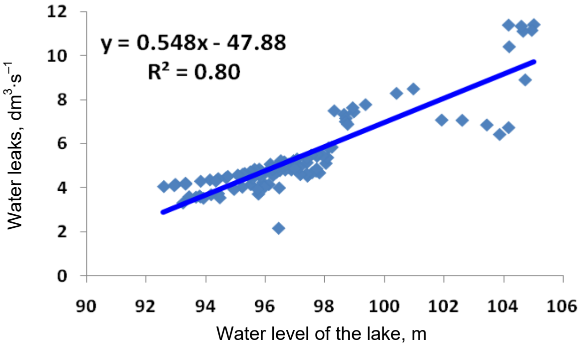

Fig. 8. Leakage ($dm^3 \cdot s^{-1}$) as a function of reservoir level (m); source: own study

shows data for the hydrological years 2005–2006. Figures 6 and 7 are discussed in more detail below.

Figure 6a shows that the flow rate through the left bank exceeded 4.3 $dm^3 \cdot s^{-1}$ in February 2004, reaching 5.98 $dm^3 \cdot s^{-1}$ in May 2004. The flow rate subsequently fell, due to the reduction in the volume of water in the reservoir, reaching 0.81 $dm^3 \cdot s^{-1}$ in January 2006. Figure 6b shows that the flow rate through the right bank exceeded 4.6 $dm^3 \cdot s^{-1}$ in February 2004, reaching 5.98 $dm^3 \cdot s^{-1}$ in May 2004. Like the left bank, the reduction in the volume of water in the reservoir led to a significant fall in the flow rate, reaching 2.25 $dm^3 \cdot s^{-1}$ in November 2006. Figure 7 shows total leakage flow rates. This follows trends for each bank. A minimum value 8.5 $dm^3 \cdot s^{-1}$ was recorded in February 2004, reaching 12 $dm^3 \cdot s^{-1}$ in May 2004. Like the two banks, levels subsequently fell due to falling water levels in the reservoir, reaching 2.18 $dm^3 \cdot s^{-1}$ in January 2008.

Figure 8 shows variation in flow rate as a function of the reservoir level for all hydrological years. Flow increases linearly with the water level. The two highest correlation coefficients (0.80 and 0.90) were calculated for the hydrological years 2004–2005 and 2005–2006 (Fig. 9). Figure 8 shows that flow rates increase consistently up to a reservoir level of 98 m, beyond which there is a more rapid increase. This could be explained by the fact that up to 98 m, flow is governed by Darcy's law and depends on the permeability of the massif. Above 98 m, underground flows no longer follow this law and instead pass through highly permeable layers or faults. This increase was particularly remarkable for the hydrological years 2004–2005 and 2005–2006. Increasing hydrostatic pressure, due to the progressive increase in the reservoir level resulted in a notable decrease in load. This resulted in the deterioration of the rock massif at the

Dates

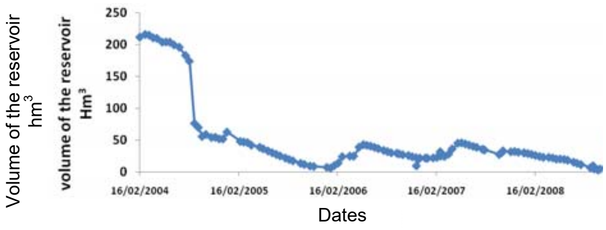

Fig. 10. Reservoir volume (hm^3) in 2004–2008; source: own study

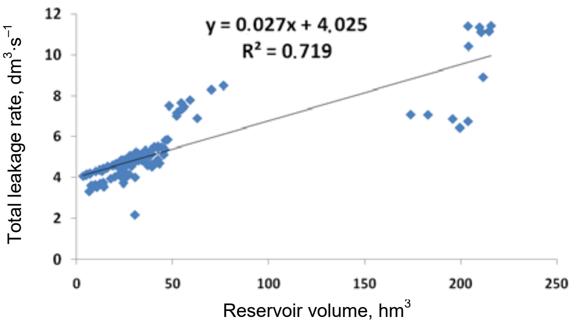

Fig. 11. Leakage (dm^3·s^{-1}) as a function of reservoir volume (hm^3); source: own study

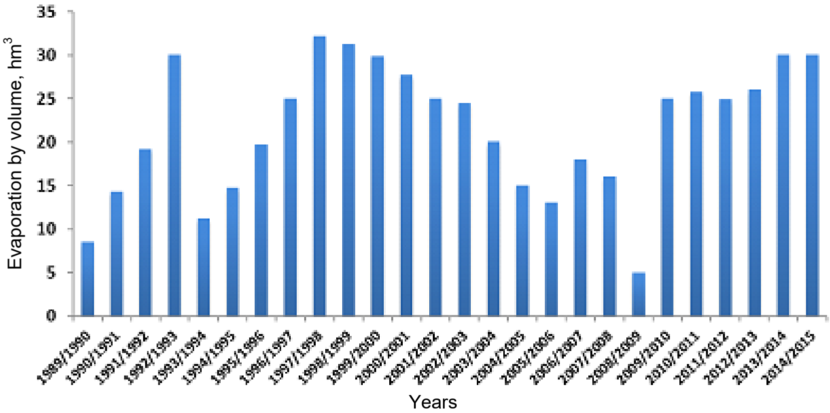

Fig. 12. Evaporation (hm^3) in 1989–2015; source: own study

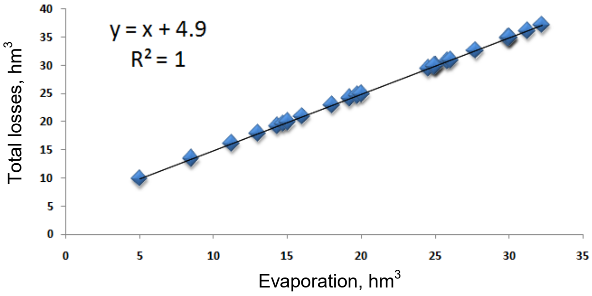

Fig. 13. Evaporation (hm^3) as a function of total losses (hm^3); source: own study

dam site, which translated into significant cracks [ANBT 1988–2015b; BENFETTA 2007; BENFETTA, REMINI 2008].

Figure 10 shows the variation of the volume of the reservoir from 2004–2008. Overall, the volume falls to drought conditions. Furthermore, Figure 11 shows how leakage falls as a function of the reservoir's volume and shows that low rates are closely correlated ($R^2 = 0.72$).

The upstream body of water at the foot of the dam is separated from the basin by a cofferdam. Although leaks are observed in the joints of the injection and drainage galleries of both banks, they are much more significant in right bank. This is because the right bank is in contact with the reservoir, while the left bank is in contact with the body of water located upstream of the dam. Leakage in the two galleries in creases as a function of rises in the reservoir level and decreases due to sealing after a long period [ANBT 1988–2015b; TOUMI, REMINI 2004]. Some leaks are sealed by the adhesion of molten limestone. The initial design of the dam did not include any devices to measure such leakage. These leakages are also due to the presence of a strong hydraulic gradient. However, the increase of this rate in time and for the same water level of the lake indicates deterioration of the rock mass forming the support of the dam. The rate of leakages was almost on the increase in time and especially when the water level in the reservoir is above the coast 98 m. This could be explained by the fact that the increased hydrostatic pressure resulted in a deterioration of the bedrock by the appearance of large cracks. It is due to the degraded state of the geological layers. The solution is to record the flow rate at the exit points of galleries in the right and the left banks. Additional test points would enhance the reliability of measures and make it possible to differentiate leaks in the various galleries (injection, drainage and access). It is also important to observe the progress of cracks, which can expand if the reservoir level rises (due to increased water pressure) [ANBT 1988–2015a].

LOSSES DUE TO EVAPORATION

The analyses presented here are based on operational data provided by the ADNT for the period 1989–2015 [ANBT 1988–2015b]. Figure 12 shows losses due to evaporation. These range from 5.0–32.2 hm^3·year^{-1}, with an annual average of 21.6 hm^3·year^{-1}. Figure 13 shows evaporation as a percentage of total water losses. Total losses range from 9.9–37.1 hm^3·year^{-1}, with an annual average of 26.50 hm^3·year^{-1} and there is a very close correlation with evaporation ($R^2 = 1$).

From 1988–2008, sedimentation volume was 112.5 hm^3, with a forecast annual average of 4.6 hm^3. In 2008, sediment represented approximately 25% (112.5 hm^3) of the dam's initial capacity. In 2015, this volume was estimated to be 144.7 hm^3 [ANBT 1988–2015a; TOUMI, REMINI 2004]. The Algerian Office of

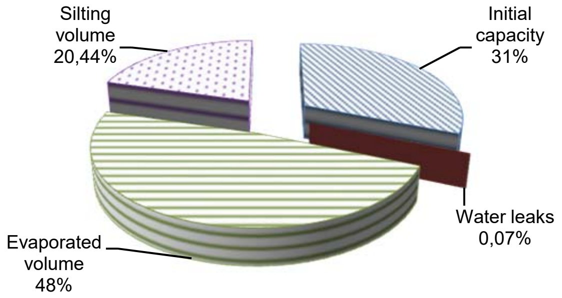

Fig. 14. Sources of water loss in 1998–2004; source: own study

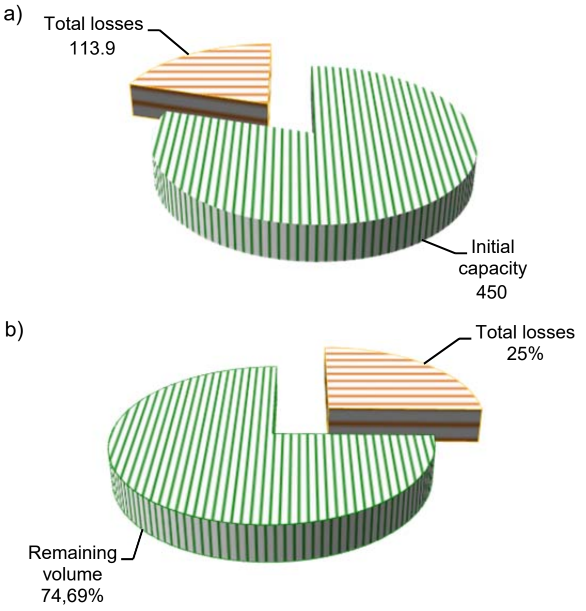

Fig. 15. Total water losses in 1998–2004: a) in hm^3, b) in %; source: own study

Education launched a study in June 2003 to evaluate the storage capacity and monitor sedimentation at the dam consisting of bathymetric and topographic surveys. Depth profiles were established at 50-metre intervals in the area 1,000 meters from the dam, and at intervals of 100 m beyond this limit. The bathymetric survey was conducted between 20 January and 10 February, 2004, covering a total area of 1,319 hectares. Taking its initial capacity as a reference, the reservoir had lost about 91.72 hm^3 of its capacity in March 2004 (approximately 20.4%). This corresponds to an average loss of about 6,114,600 $m^3 \cdot year^{-1}$. Its current volume is about 358.28 hm^3 [ANBT 1988–2015b].

TOTAL LOSSES

Not only losses have increased over time, but also the problem is ongoing, and the situation is deteriorating. Taking 2015 as a baseline, estimated losses are as follows (excluding losses from the bottom outlet):

$$Lv = Iv + Ev + Dv \tag{1}$$

where: Lv = volume of losses; Dv = dead volume (4.6 $hm^3 \cdot year^{-1}$); Iv = infiltrated (leakage) volume (0.3 $hm^3 \cdot year^{-1}$); Ev = evaporated volume (21.6 $hm^3 \cdot year^{-1}$).

Based on data from the bathymetric survey conducted in 2004, the dam has lost 92 million m^3 of water over a period of 15 years. This is due to excessive sedimentation, leakage (annual average 0.3 hm^3) and evaporation (annual average 21.6 hm^3). Total losses for 2004 are estimated at 113.9 hm^3, which represents about 25.31% of total capacity (Figs. 14–15). Total losses by sector at Gargar dam are as follow:
- remaining volume – 32%,
- volume loss to leakage – <1%,
- volume loss by sedimentation – 20%,
- volume loss to evaporation – 48%.

Taking 2015 as the baseline, current losses are estimated as:
- average inter-annual leakage of 0.5 hm^3.
- average inter-annual evaporation of 21.6 hm^3.
- estimated sedimentation of 144.7 hm^3.

This makes a total loss of 166.8 hm^3, representing about 37% of total capacity (Figs. 16–17, Tab. 1). The most important factors are leakage and sedimentation, which has reduced capacity to a remarkable extent. These problems must be addressed as a priority.

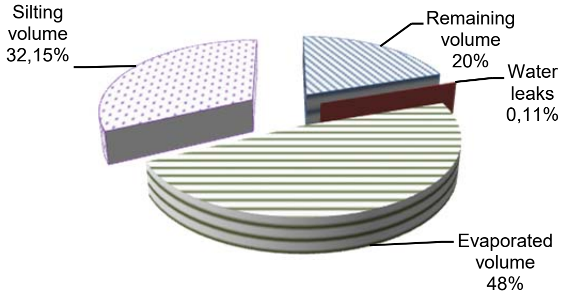

Fig. 16. Percentage water losses by sector in 1988–2015; source: own study

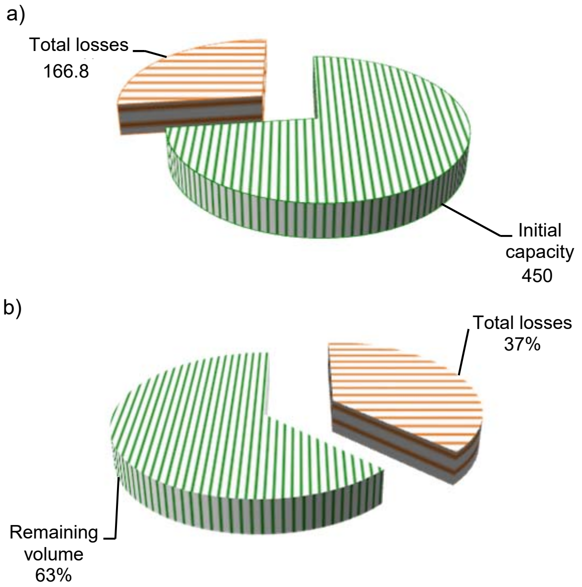

Fig. 17. Total water losses in 1988–2015: a) in hm^3, b) in %; source: own study

Table 1. Total losses by sector at Gargar dam

Year	Remaining volume	Volume loss to leakage	Volume loss by sedimentation	Volume loss to evaporation	Total losses hm^3	Total losses %
	$hm^3 \cdot year^{-1}$					
2004	336.1	0.3	4.6	21.6	113.9	25.3
2015	283.2	0.5	4.6	21.6	166.8	37.0

Source: own study.

CONCLUSIONS

Leakage, sedimentation and evaporation are the three phenomena that have reduced the capacity of the Gargar dam; moreover, these problems threaten the dam's stability. Our work examines the sources of these losses. We conclude that correlations between hydraulic parameters confirm the presence of leaks in both banks downstream of the dam, exacerbated by the presence of cracks. These leaks can be clearly seen. Flow rates increase linearly with the level of the reservoir. High correlation coefficients (0.80 and 0.90) for the hydrological years 2004–2005 and 2005–2006 confirm this finding. Leaks are especially worrying as flow rate continues to increase due to the deterioration of certain impermeable zones caused, in turn, by hydraulic erosion or chemical corrosion. Our study established that the origin of these leaks is a lack of impermeability at the point where the reservoir meets the ground water. Therefore, the proposed solution consists of improving the impermeability of both banks with a curtain injection. These leakages are also due to the presence of a strong hydraulic gradient. However, the increase of this rate in time and for the same water level of the lake indicates deterioration of the rock mass forming the support of the dam. The rate of leakages was almost on the increase in time and especially when the water level in the reservoir is above the coast 98 m. This could be explained by the fact that the increased hydrostatic pressure resulted in a deterioration of the bedrock by the appearance of large cracks. It is due to the degraded state of the geological layers. Water leaks at the level of this dam are more complex, so more studies are necessary to solve this problem. In addition to the considerable losses caused by leakage (estimated to an average 0.5 hm^3 /year), losses due to sedimentation and evaporation (respectively 21.6 hm^3 and 144.7 hm^3 for 2015) account for a total of 166.8 hm^3 – representing 37% of total capacity It is therefore necessary to address the loss of storage capacity in order to avoid environmental damage and ensure that the project remains financially viable. The situation is very disturbing because water leaks result in considerable losses and threaten the stability of the dam. Face to these facts, solving this problem is deemed necessary to increase the storage capacity and assure the safety of this dam. For that purpose, the proposed treatment consists in improving the waterproofness in the two banks by a grout curtain. It is also necessary to solve the problems of the mudding of the reservoir and the evaporation by the reforestation to reduce the losses to water.

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Przecieki wody, sedymentacja i parowanie w suchych regionach: przypadek zapory Gargar w Algierii

STRESZCZENIE

Badania prowadzono w celu oceny całkowitych strat wody w zaporze Gargar, trzeciej co do wielkości zaporze w Algierii, w związku z zamulaniem zbiornika, intensywnym parowaniem i przeciekami wody. Analizowano zmienność przecieków w funkcji poziomu wody w zbiorniku i określono ilościowo straty spowodowane przeciekami, sedymentacją i parowaniem. Realizowano wyjazdy terenowe i korzystano z danych otrzymanych z Algierskiej Agencji Zapór i Transferów Wody, aby oszacować objętość strat, poziom wody w zbiorniku, sedymentację i parowanie w latach 1988–2015. W niniejszej pracy przedstawiono uaktualnione wyniki w tym zakresie. Na całkowite ubytki wody uśrednione z okresu 1988–2015 i oszacowane na 23 mln m^3 na rok składały się przecieki (0,3 mln $m^3 \cdot rok^{-1}$), parowanie (18 mln $m^3 \cdot rok^{-1}$) i objętość martwa zbiornika (4,6 mln $m^3 \cdot rok^{-1}$). Całkowite straty oszacowane w odniesieniu do roku 2004 wynosiły 113,9 mln m^3, a w roku 2015 wzrosły do alarmującej wartości 166,8 mln m^3. Autorzy niniejszej pracy sugerują poprawę szczelności przez użycie betonowych ekranów oraz ograniczenie zamulania i parowania poprzez zalesianie terenu przyległego, aby zwiększyć pojemność retencyjną zbiornika.

Słowa kluczowe: *parowanie, przecieki wody, sedymentacja, strefy suchego klimatu, zapora Gargar*