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## Cleanup and valuation of waters of the aquifer of M'zab Valley (Algeria)

Cheikh OULED BELKHIR<sup>1) AB</sup>, Boualem REMINI<sup>2) ABCDEF</sup>

<sup>1)</sup> Superior National School of Agronomy, Department of Rural Engineering, Algiers 16000, Algeria; e-mail: ouledbelkhircheikh@yahoo.com

<sup>2)</sup> University of Blida, Department of Water Sciences, Blida 9000, Algeria; e-mail: reminib@yahoo.fr

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### Abstract

The M'zab valley is a hyper arid region of average rainfall not exceeding 100 mm per year. However, the rare floods that occur in M'zab River drain large volumes of surface water. Thanks to the genius of the local population, traditional dams were made for artificial recharge of groundwater. Grace of traditional wells drilled in the valley, farmers irrigate their palm groves and gardens. However, since more than half a century, the contribution of deep drilling for the exploitation of the aquifer of the Continental Intercalary posed environmental problems. On the basis of investigations and surveys of the local population during the years 2010, 2011, 2012 and 2013, it appears that these modern techniques in water catchment caused harmful consequences to the region like the rising of water consumption, pollution of groundwater and soil salinity. Solutions and recommendations are outlined in this article.

**Key words:** *aquifer, dam, environment, ground water, pollution, the M'zab Valley*

### INTRODUCTION

In the M'zab Valley, flooding in times of floods and pollution of ground water are the main topics of concern to local inhabitants and authorities [OULED BELKHIR 2002]. Mozabites developed over century's original architecture, listed as a world cultural heritage. This art is reflected both in the overall structure of the various Ksars that in the architecture of houses and mosques [Delta 2006]. Hydraulic developed by Mozabites over the centuries has been the subject of admiration by scholars. Hydraulic works were made in the M'zab Valley as weirs, dams, tunnels and shafts. The wadis have been built with an original know how. Through a complex network of seguias, pipes and allows dispatchers to drive the water gardens [DUBIEF 1963]. Part of this water recharges the groundwater. In times of drought, Mozabites capture groundwater by traditional wells by appealing the

work of animals (donkeys, mules, camels). The contribution of new techniques of water harvesting (boreholes and pumps) has unbalanced the M'zab Valley. This new situation has caused the rising water in several areas of the M'zab Valley as if the Souf Valley [BENGURGOURA LARADJ, REMINI 2014].

### STUDY AREA AND FIELD MISSIONS

#### LOCATION OF THE M'ZAB VALLEY

The M'zab Valley is located south west of Algeria, 600 km from Algiers (Fig. 1). Five ksours were built on M'zab valley: El'Atteuf in 1012, Bounoura in 1046, in 1053 Ghardaia, Melika and Beni in 1124 Isguen in 1347 [BENYOUCEF 1986]. The area of five ksours is around 67 ha. The valley runs through a limestone plateau and ksours are on the rocks bordering the river where the soil consists of loam and

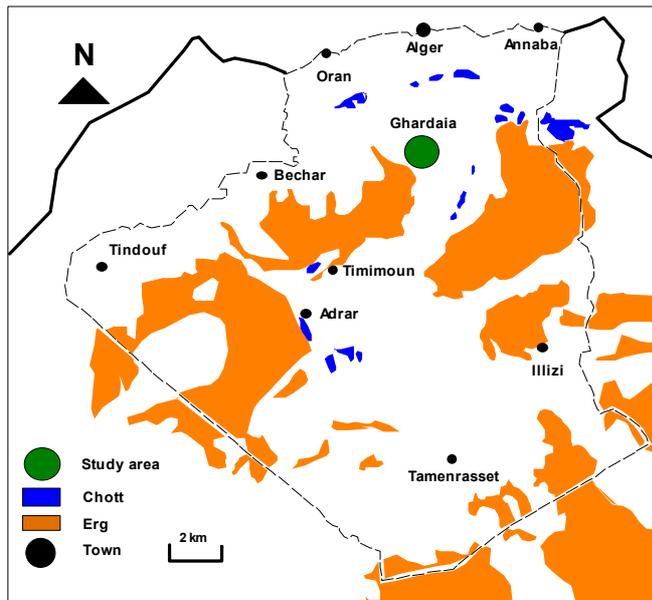


Fig. 1. Location of the study area; source: own elaboration

sand. Agriculture is the main activity in the valley. Found in a date palm garden, fruit trees, vegetable crops and fodder. Concerning water resources in the region, surface water occur in flood periods, which recharge aquifers by conventional techniques [OULED BELKHIR 2002].

#### MISSIONS IN THE OASES OF M'ZAB

We have made several trips to the oases of M'zab during the years 2010, 2011, 2012 and 2013 Surveys of the population ksours were conducted during our missions. During these missions we observed a deterioration of the M'zab Valley following the release of sewage into the river M'zab. Traditional structures are deteriorating from one year to another. Dams traditional of Bouchen and Touzouz are silted following the deposition of sediments.

### RESULTS AND DISCUSSION

#### THE HYDRAULIC STRUCTURES OF M'ZAB VALLEY

In the M'zab valley, there are a multitude of hydraulic works for the water harvesting and recharge of groundwater. The water table of the M'zab Valley is the main irrigation resource for the palm. Their charging is ensured by the infiltration of flood waters of the valley. The recharge of the aquifer is accelerated by dams locally called Ahbas that store floodwaters. These waters seep into the ground beneath to fill groundwater.

##### The dam on El Abiod River

El Abiod River upstream of the confluence with the river of M'zab was recently carried out just after the famous flood of October 2008. It is intended for

flood control. This structure essentially consists of a masonry wall supported by buttresses and a raft downstream. It is provided on the right bank of a weir equipped with a flat valve. Its objective is to ensure a recharge of the water table whose exploitation allows irrigation of surrounding agricultural areas.

##### The dam of AhbasAjdid

It is among the oldest dam made along the M'zab River. It is intended for replenishing of the water table (Phot. 1). The dam consists essentially of a spillway sill at two levels which is closed directly on the existing track and the right bank which is made of a masonry wall supported by buttresses.

##### The dam of El Atteuf

This is the dam the most emblematic of the M'zab valley. The dam is to cross the wadi, is based on the slope on the right bank. The dam has a spillway and a topographical closure consists of a stepped embankment on a masonry wall (Phot. 2). The main dam has suffered a major breach after the flood of 2008. Repairs and reinforcement has been made to restore its integrity. The El Atteuf dam is the last structure of M'zab River. It plays a very



Phot. 1. Dam of Ahbas Ajdid (photo. C. Ouled Belkhir)



Phot. 2. El Atteuf dam (photo. B. Remini)

important role in the storage of flood water and recharging groundwater. With each flood, the wells in the area are filled with water. The dam of El Atteuf was made for the protection of the palm and recharging groundwater.

**ENVIRONMENTAL DEGRADATION**

**Flood**

Floods nuisance of Wadi M'zab are dangerous and often cause adverse effects in the palm and crossing the urbanized areas. Floods cause damage to homes and residents. Floods are also the cause of livestock losses and sometimes human lives (floods of June 1991, September 1994, June 2004 and October 2008). The flows from the side Wadis also pose risks to the population [OULED BELKHIR 2002; ROCHE 1996].

**The waste water**

Over the years, discharges of sewage into the M'zab River increased in an exceptional way. In many places, sewage encumbers the bed of the river and pollute groundwater. This is due either to faulty connections (such as the connection of Ben Ghanem neighborhood to the main drain) or the absence or malfunction of the main. In areas where the main collector is not yet built, bleedings were performed in the bed of the wadi to channel wastewater to the next completed section of the drain (Phot. 3 and 4). Recharging groundwater percolation is thus favored and the upwelling of this accelerated table (Phot. 5).

**Interference of drinking water systems and wastewater**

The distribution of the population on both sides of the valley involves many crossed the bed of the wadi by the supply network of drinking water. However, some areas of the river are choked with sewage stagnant (Phot. 6). This is dangerous for the populations served, given the risks of waterborne diseases that made them run.

**Solid waste**

Wild dumps bulky bed of the M'zab River (Phot. 7). During floods, these wastes are arrested by the valley crossings, thereby significantly reducing the flow section of the wadi and causing overflows on the banks. The solution can only come from the establishment of an effective waste collection service and the involvement of the populations concerned. Furthermore, it is important that such wastes are discharged to a sanitary landfill.

**IMPACT OF UPSTREAM ROLLING WORKS**

The objective of these dams is to reduce peak flood flows. Until millennial flood frequency, the maximum flow rate released by the dams on El Wadi of El Abiod and Haimeur will be 20 m<sup>3</sup>·s<sup>-1</sup> and the

released downstream of the dam of Bou Brik will be 5 m<sup>3</sup>·s<sup>-1</sup>. For frequency of floods rarer still, as the flood of October 2008, the flows released downstream will be as follows [ROCHE 1996] (Tab. 1).

**Table 1.** Peak flow of the thousand year flood at the dam

Dam	Discharge, m <sup>3</sup> ·s <sup>-1</sup>	
	natural discharge	rolled discharge
El Abiod	1 400	240
El Haimeur	1 030	250
Bou Brik	500	75

Source: own study.

At the confluence of Wadi of El Abiod, El Haimeur and the right of El Atteuf dam, approximately at the beginning and the end of the urbanized area, peak flows of the hundred-year flood, natural and rolled by the upstream dams are following: OULED BELKHIR [2002], ROCHE [1996] – Table 2.

**Table 2.** Peak flow of the century flood at the confluence: El Abiod River – El Haimeur River and at the dam of El Atteuf

Measurement points	Discharge, m <sup>3</sup> ·s <sup>-1</sup>	
	natural discharge	flow with upstream dams
Confluence	690	170
El Atteuf dam	780	290

Source: own study.

The protective effect of these works is extremely important since it allows dividing the cutting edge of design flood flow by a factor between 2.7 and 4.0. Depending on the position of the point considered along the valley, the effect of the intermediate catchment gaining in importance as one moves downstream. Thanks to this contribution and downstream facilities of the bed of the river, property damage and loss of life can be avoided. The other impact of these dams is to extend the flow time in the bed of the river. Thus for a centennial event, the flow time for floods occurring at various dam sites is amended as follows (Tab. 3).

This has two consequences: the water table recharge downstream of barrageset possible re-use of flood waters. This feature, which connects these deductions tradition of flood storage and spreading of dams built for centuries by Mozabite civilization, allows through a temporary adjustment of floodwaters to manage these contributions and hold and flexible in the project situation. It also limits this provision risks to traditional dams built along the river and mainly the side intakes such as the Bouchen dam (Phot. 8) [OULED BELKHIR 2002; ROCHE 1996]. In addition Mozabites enjoying of flood waters for irrigation of the palm. Thus they have realized a flood of watershed-based of foggaras system [REMINE *et al.* 2012].

For over seven centuries, the hydraulic system of the M'zab Valley is based on the principle of his artificial recharge of groundwater. All the dams (Bouchen, Touzouz, Ahbas Ajddid, El Atteuf...)



Phot. 3. Discharge of waste water into the bed of the wadi downstream Ahbass Ajdid (photo. *B. Remini*)



Phot. 4. Bloodletting in the bed of the river of M'zab El Attetufo channel waste water (photo. *C. Ouled Belkhir*)



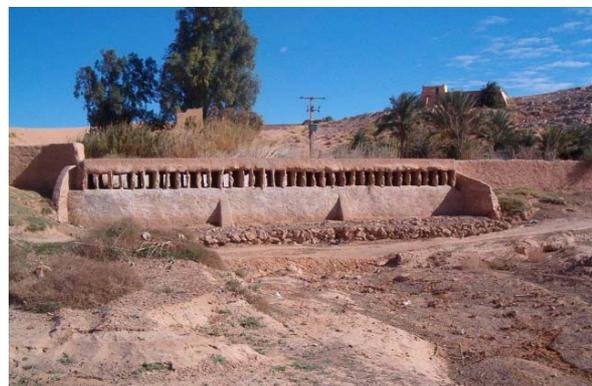
Phot. 5. Wastewater into the bed of the river, downstream of the wastewater treatment plant (photo. *C. Ouled Belkhir*)



Phot. 6. Conduct of drinking water through the air zone sewage stagnation (photo. *C. Ouled Belkhir*)



Phot. 7. Wild discharge zone in the bed of the wadi in Ghardaia (photo. *C. Ouled Belkhir*)



Phot. 8. Water outlet at Bouchène dam (photo. *B. Remini*)



Phot. 9. Sharing system floodwaters (photo. *B. Remini*)



Phot. 10. A view of the water treatment plant by lagoons the M'zab Valley (photo. *C. Ouled Belkhir*)

**Table 3.** Flow time of year flood downstream of dams

Dam	Time, hours	
	natural time	duration of the rolled flood
El Abiod	25	250
El Haimeur	19	150
Bou Brik	7	105

Source: own study.

realized on the river M'zab are for recharging the water table. On arrival of a flood, the water flows through the apertures and then underground galleries to reach the channels network and then the glass (Phot. 9).

### IMPACT OF THE WORK IN THE BED OF THE RIVER AND ON THE BANKS

After the flood of 2008, the bed development work and reinforcement of the banks have been initiated in order to protect nearby homes against flooding. The design of hydraulic structures along the valley used to protect settlements against a hundred-year flood frequency. For example, the return period for the flood of 2008 can be estimated at about 100 years. Currently, the river became an M'zab discharge area wastewater deposit rubble and garbage [BENSSAAD 1998].

### DISCHARGES DOWNSTREAM OF THE WASTEWATER TREATMENT PLANT BY LAGOONS

If today, the oasis of El Atteuf is watered surplus water of the M'zab River dumped by the dams of Ghardaia, Mlika, BeniIsguen and Bounoura, the oasis of El Atteuf receives all wastewater of four oases. The role of the wastewater treatment plant by lagoons in the clean water carried downstream of the oasis has been treated in this study. The health situation was becoming critical M'zab. First, the water table is polluted because of seepage from irrigation and wastewater discharges. Furthermore, the combined effect of lower water withdrawals and increasing the recharge, the aquifer tended to strongly back into some low-lying areas such as the palm, causing dieback palms. Local authorities have decided to set up a treatment plant by natural lagoons. On an area of 600,000 m<sup>2</sup>, a treatment plant was set up in December 2012 at the place called "Kef Edoukhan", for the management of wastewater from four oases of the M'zab Valley (Daya Ben Dahoua, Ghardaia, Bounour and El Atteuf), estimated at more than 46,000 m<sup>3</sup>·day<sup>-1</sup>. The natural lagooning plant has eight (8) aeration tanks, reinforced by three aerators basin that will be in service temporarily, according to the results of the daily analyzes of the quality of treated water, and three (3) pools decantation to ensure good degradation and two (2) finishing pools necessary for the elimination of microorganisms and the retention of solid susceptible to decantation (Phot. 10). A wastewater treatment

plant was conducted in the M'zab River near the oasis of El Atteuf. At this stage the flow of treated water not used by agriculture will be rejected in the river. The environmental impact will not be as favorable. The discharged water have the following parameters: DBO<sub>5</sub> ≤ 50 mg·l<sup>-1</sup>, SM ≤ 120 mg·l<sup>-1</sup>, Faecal Coliforms (FC): CF ≤ 5.10<sup>4</sup> FC·(100 ml)<sup>-1</sup>, Helminth eggs: ≤1 l<sup>-1</sup> [LALLEMAND, ROUX 1995]. The conditions of the fauna and flora will be greatly improved over a few kilometers. The development of vegetation will however be controlled close to the treatment works to avoid negative impacts on flood conditions of passage.

### WASTEWATER REUSE FOR AGRICULTURE

The potential evapotranspiration (*ETP*) is around 2 m per year in Ghardaia. The extreme values of the *ETP* occurring in July and August are about 500 mm, more than twice as much as during the cold season. These differences are not without consequences on the agricultural practice. The report rain/*ETP* is less than 0.03, which is extremely low by the standards of temperate countries. The large deficit must be offset by appropriate irrigation [OULED BELKHIR 2002]. The reduction in *ETP* within a cultivated plot depends on a priority of the precautions taken at the time of its furnishings and its provision in the topography of the site, its orientation to the prevailing wind, the breeze afforestation winds, the succession of cultures and the operating system (high seeding) [MICHEL 1993; OULED BELKHIR 2002]. In the Sahara, it is necessary to calculate the cheapest irrigation doses at different stages of culture by applying the adjustment coefficients called structural coefficients [MICHEL 1993]. The breaks in irrigation will not have the same consequences on yields depending on when they occur, they can be catastrophic for culture at certain times of her cycle. Plants are often under stress in terms Saharan when sufficient blood flow, hence the need for adequate water supply, leading to privilege, with date palms, rather winter crops (barley and vegetables) planted in September and harvested in April. Advanced needs must be taken into account in the calculation of an irrigation water system. In summer it assumes volume of 2500 m<sup>3</sup>·ha<sup>-1</sup>·month<sup>-1</sup> which is about 700 l·tree<sup>-1</sup>·day<sup>-1</sup>, for an orchard of 120 palms·ha<sup>-1</sup> [Delta 2006]. Based on a volume of water treated 23 000 m<sup>3</sup>·day<sup>-1</sup> at the end of work and 46 000 m<sup>3</sup>·day<sup>-1</sup> project on the horizon, palm of the area it will be possible to irrigate respectively 275 hectares and 550 hectares. To allow the Administration to support a feasibility study of implantation of an agricultural perimeter site Kef Doukhane irrigated with treated wastewater, the terms of reference for such a study are given in materials suspended and the risk of soil clogging. The irrigation system should take into account the content of suspended matter that we will exit lagoons, of the order of 120 mg·l<sup>-1</sup>. To avoid the risk of clogging of irrigation systems and limit soil

sealing possibilities, it is important to use drip irrigation systems with irrigation equipment with large openings [BENYOUCEF 1986].

### FERTILIZING ELEMENTS

The wastewater contains many nutrients which the plant needs for growth, such as nitrogen, phosphorus, potassium, zinc and copper. For wastewater containing a nitrogen content of  $15 \text{ mg}\cdot\text{l}^{-1}$ , application of 100 mm corresponds to a nitrogen intake of about  $15 \text{ kg}\cdot\text{ha}^{-1}$ . As with the use of fertilizers, it is necessary to avoid excesses, and we must strive to give the plant the amounts of water needed for its development, excess nitrogen or potassium can infiltrate into the soil and into the groundwater [FONTAINE 1969; LALLEMAND 1995].

### RISKS OF CONTAMINATION

The conditions of secondary treatment by lagoons can guarantee a water quality that can be used for irrigation not intended to be eaten raw crops. The permanence of good management of the treatment system is a necessary provision to prevent possible pollution. Care must be taken to avoid contamination with pathogenic bacteria operator personnel, and consumers. The irrigation system must be designed to limit direct contact with the treated effluent [LALLEMAND-BARRES, ROUX 1995].

### CONCLUSION

The positive impacts of the proposed decontamination and recycling are:

- the guarantee the protection of property and vis-à-vis populations flood: the town is completely immune to this type of event up to a hundred-year frequency, thanks to the temporary retention structures in flood upstream and amenities of the bed of the river downstream;
- the recharge of the water table close to laval temporary flood retention structures;
- the possibility for an extended period of reuse, with traditional infrastructure, flood waters, thanks to the works of the aforementioned rolling effect;
- the protection of groundwater against pollution from waste water, improved sanitary conditions;
- clean the M'zab Valley throughout the urbanized area and downstream of the dam of El Atteuf, also

improving the sanitary conditions and the visual and olfactory impact;

- rehabilitation of the bed of the M'zab River, leading to a new image in the urban landscape, in particular by avoiding to consider it as a dumping ground;
- the wastewater treatment outside inhabited areas;
- the possible reuse, at least in part, treated water for agricultural irrigation with an area of 550 ha of palm trees on the horizon of the project;
- the re-treatment sludge to agricultural land use purposes;
- offer the simplest and most reliable solutions possible: in particular this was an argument for the choice of wastewater stabilization ponds.

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**Cheikh OULED BELKHIR, Boualem REMINI**

**Oczyszczanie i ocena poziomów wodonośnych doliny M'zab w Algierii**

STRESZCZENIE

**Słowa kluczowe:** *dolina M'Zab, ochrona środowiska, tama, warstwa wodonośna, woda gruntowa, zanieczyszczenie*

Dolina M'zab to suchy region charakteryzujący się niewielką ilością opadów (poniżej 100 mm rocznie) i rzadko zdarzającymi się gwałtownymi powodziąmi, które niosą ogromne ilości wód. Dzięki zdolnościom miejscowej ludności w dolinie rzecznej powstawały tradycyjne zapory pozwalające uzupełniać zasoby wód podziemnych. Tradycyjne studnie wiercone w dolinie umożliwiają rolnikom nawadnianie gajów palmowych i ogrodów. Jednakże od ponad pół wieku eksploatacja głębokich odwiertów z kredowych warstw wodonośnych stwarza problemy środowiskowe. Na podstawie badań z lat 2010–2013 i ankietowania miejscowej ludności można wysnuć stwierdzenie, że nowoczesne techniki wykorzystywania wody w zlewni rodzą poważne konsekwencje dla regionu w postaci wzrostu zużycia wody, zanieczyszczenia wód gruntowych i zasolenia gleby. W niniejszym artykule przedstawiono rozwiązania i zalecenia w tym zakresie.