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# Impact study of Beni-Haroun dam on the environmental and socio-economic elements in Kébir-Rhumel basin, Algeria

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## Abstract

Surface water of Kébir Rhumel basin is indispensable for domestic and industrial needs of this region. Industrial development, with water excessive use and chemical products, in production and industrial treatment, and not sustainable fertilizers in agriculture, constitutes a serious threat to maintain our resources of good water quality. The majority of domestic and industrial wastewaters of the region, discharged to the stream water of Kébir Rhumel basin, promote the water enrichment in nutritious elements, phosphorus and nitrogen and particularly, the resulting increase in the aquatic primary production, mainly the planktonic or benthic algae. As a result, the physical and chemical properties of water deteriorate.

This basin allows construction of the largest dam in Algeria “Beni-Haroun dam”. The infrastructure that was one of the greatest challenges of Algeria is now a reality. Hydraulic complex of Beni-Haroun remains a strategic and major achievement in the development program of water resources sector. This enormous building was constructed in the territory of the Wilaya (province) of Mila, used to meet water needs, with four million inhabitants, of eastern Algeria and other neighbouring regions that have suffered from lack of water consumption, especially in summer. In addition, it will irrigate over 42 000 ha, going thus to the several plains.

Integration of sociological and environmental concerns into dams design is a recent phenomenon. It is considered at the impact study level, during which the dam study project is accompanied by a survey to assess project impact on natural environment and socioeconomic development.

**Key words:** basin, Beni-Haroun dam, hydraulic-system, irrigation perimeter, Kebir-Rhumel, sediment transport, socio-economic

## INTRODUCTION

In Algeria, water resources constitute one of the main richness on which country prosperity and development depend. Unfortunately, these resources are threatened by the loss of dams storage capacity due to siltation phenomenon.

Siltation or aggradation is the natural consequence of watershed degradation. Actually, it is a concern for planners and operators of a country characterized by a high population rate, which is necessary to conserve existing water reserves.

Maghreb countries as Algeria, Morocco and Tunisia are characterized by water resources scarcity, a characteristic that they have in common with all arid and semi-arid countries. These countries are in a mountainous area (Telliyan), characterized by an aggressive climate with alternating wet and dry years and heavy (intense) and devastating autumn rains for the soils, especially since they occur at a period when the vegetation is reduced or absent and the soil has been loosened by tillage (plowing). Thus, consequences are firstly, violent and brutal autumn floods which create strong removal and secondly, erosion rate in the catchment basins which is important. For example, accord-

ing to HEUSCH and MILLIES [1971] results on the Maghreb catchment basin, abrasion rate is  $800 \text{ Mg} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ , while that obtained by SOGREAH [REMINI *et al.* 1996] is even higher and is about  $1\,250 \text{ Mg} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ . TOUAIBIA *et al.* and TARFOUS *et al.* [2001] works also show that large amount of sediment transport in Algerian rivers reached dams during flood periods, particularly in autumn season. In Algeria, the specific erosion rate reaches the highest values in North of Africa, according to DEMMAK [1982], they exceed  $2\,000 \text{ Mg} \cdot \text{km}^{-2}$ .

Algeria is characterized by water resources scarcity as all arid and semi-arid areas. Population and industrial activities growth polluted domestic and industrial effluents, deteriorated water resources quality, and compromised receiving environment disequilibrium [NELSON 1994; SMITH 2001]. Many elaborated works on surface water pollution have shown high phosphorus and nitrates concentrations in rivers [NEAL *et al.* 2004; PAUWELS, TALBO 2004], particularly during storm events. Stream-water nutritive enrichment has led to watery plants excessive growth, biotic structure change, and dissolved oxygen reduction [CAPBLANCQ, DECAMPS 2002; RYDING, RAST 1994]. This eutrophication phenomenon is a growing problem particularly in rural area [NEAL, WHITEHEAD (ed.) 2002; PAUWELS, TALBO 2004].

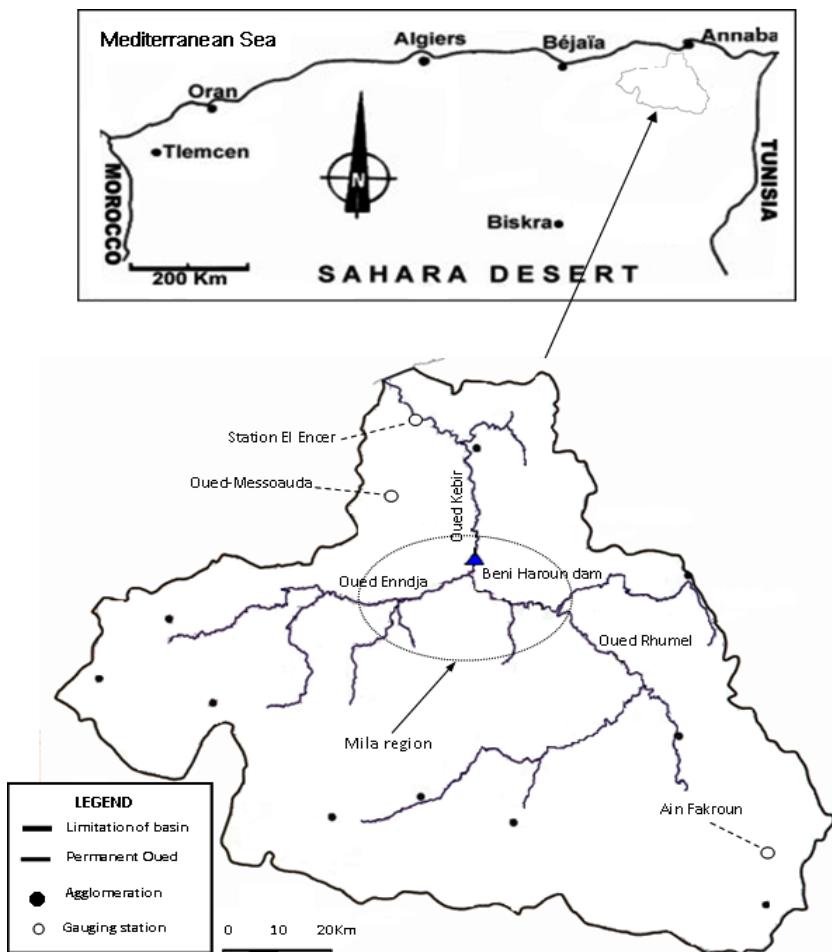


Fig. 1. Location of gauging stations and the Beni-Haroun dam in the Kébir-Rhumel Basin; source: own elaboration

The integrated hydraulic system of Beni-Haoun is intended to meet the needs of drinking water to several cities and the development of land suitable for irrigation, identified at the Southern High Plains in the Wadi Kebir-Rhumel basin of Constantine.

The present study aims to analyse the monitoring of environmental and socio-economic impacts generated by Beni-Haroun dam project construction, located on Kébir-Rhumel catchment area, in north-eastern Algeria. This huge dam of about 980 mln  $\text{m}^3$  and a Roller-Compacted Concrete (RCC) dike of 125 m height provides drinking water to 4 mln inhabitants and irrigates about 42 ha of agricultural lands.

During this work, many documents related to this project were consulted and several data from hydraulic and administrative departments regarding Beni-Haroun dam and their environment (National Agency of Dams and Transfers, Fr. Agence nationale des barrages et transferts – ANBT, Hydric Water National Agency, Fr. Agence nationale des ressources hydrauliques – ANRH, Hydrographic Basin Agency, Fr. Agence des bassins hydrographiques – ABH, Direction of Water Resources of Wilaya, Fr. Direction des ressources en eau de la Wilaya – DRE, National Sanitation Office, Fr. Office national d'assainissement – ONA) were collected. Regular analyses of the dam's water quality and Kebir-Rhumel basins watercourses were carried-out *in situ* and monitored over several years [MAROUF, REMINI 2014] where Beni-Haroun dam watercourse sediment loads were quantified [MAROUF, REMINI 2011]. During Beni-Haroun dam operation in 2014, continuous control and monitoring of the dam dike stability is developed.

## STUDY AREA

The Wadi-Kebir-Rhumel basin is located in eastern Algeria; it is about  $8\,800 \text{ km}^2$  surface area. The western part, called Wadi-Enndja basin, has a surface area of  $2\,190 \text{ km}^2$ , and is characterized by a mountainous topography and relatively high precipitation (about  $700 \text{ mm year}^{-1}$ ). In this basin, altitude is more than 1 400 m. However the eastern part, consisting mainly of the Wadi-Rhumel Basin, is characterized by a softer topography and moderate precipitation (about  $500 \text{ mm year}^{-1}$ ). The surface area of this basin is  $5\,490 \text{ km}^2$  (Fig. 1).

Wadi-Kebir is the result of Wadi-Enndja and Wadi-Rhumel confluence. This confluence is located at 3 km, far South, upstream of Beni-Haroun gorge. Total catchment area of Beni-Haroun's dam is of  $7\,725 \text{ km}^2$  [ANBT 2002].

The basin of Kébir-Rhumel is characterized by a Mediterranean climate and includes:

- a monomodal regime (Maritime) at basin northern part, characterized by a high winter rain precipitation and low summer precipitation;
- a transition Tellien regime (median zone of the basin), where the rainfall is most extreme in December and tends to decrease in March and April;
- a continental regime in southern part of the basin which is characterised by a heavy rainfall in spring-summer; rainfall reaches two high values – the first one in winter (December and January) and the second in spring (March and April) – this regime is in the southern high plains where the semi-arid bioclimate prevailing.

The annual average temperature is 18°C that varies approximately from 5°C in January to 25°C in August. The average precipitation near to median basin varies approximately from 7 mm·month<sup>-1</sup> in July to 80 mm·month<sup>-1</sup> in December. The relative humidity varies approximately from 50% in August to 70% between November and March [MEBARKI 1982; 1984].

Kebir-Rhumel basin presents an opposed structure which is visible through a relatively simple substratum in South. This substratum is built mainly on large sedimentary terrains where isolated limestone massifs emerge. It is also formed by a complex edifice in the North, which consists of several heterogeneous series piled upon successive tectonic phases.

We can clearly distinguish the upstream and downstream area of the basin as follows.

1. The High Plains domain: from a group of dominant marly terrain from which emerge in horst, a cretaceous limestone massive. Karstic phenomena are very developed in the South of these limestone massifs helped by the high altitude climate which prevail in these massifs and by amplitude of tectonic perturbation.

2. The South Tellian Piedmont: presents a high Miocene-Pliocene depression consisting of low hills where a dense series of ravines provide a high dissected aspect to the relief. This large basin includes some isolated limestone reliefs. In general, the continental deposits accumulated in this depression are composed of clay where it is sometimes possible to find red conglomeratic levels and limestone lacustrine.

3. The North massive Tellian: is mainly composed of Jurassic limestones and Oligocene sandstone massifs. Thick marly layers are pierced by the limestone massifs, due to a complex tectonics.

These localised lithological formations in the basin are continuously subjected to strong erosion. The calculation of specific annual erosion over the entire study period revealed the years that have contributed strongly to rapid siltation of Beni-Haroun dam. 1984 and 1990 present a maximum specific erosion value that exceeds 2 200 Mg·km<sup>-2</sup>·year<sup>-1</sup>.

In the Wadi-Enndja Basin located in the West and the North-West of the Kebir-Rhumel basin the rainy season is generally from December to May. In the Wadi Rhumel Basin, which extends from the South to the North-East of the basin, pluviometry is distributed in a uniform way throughout the year, especially as compared to the Wadi-Enndja Basin.

The infiltration properties in Wadi Rhumel Basin seem to indicate that the ground is more permeable than that of Wadi-Enndja.

The flows of Wadi-Enndja and Rhumel with their junction are not proportional to their respective draining surfaces. Because of the different hydrological and geological characteristics, the Wadi-Enndja contributions are more important than those of Wadi Rhumel.

The expansion of vegetation in the basin is limited, its main location is in the North Kebir-Rhumel basin, which consists of the forests of cork oak.

In the South Kebir-Rhumel basin, forests of green oak appear with some occurrences of Aleppo pine. In the semi-arid margins, the forest disappears and is replaced by a margin matorral on Limestone Mountains.

The physical consistency of this arrangement consists of mobilization works, transfer, treatment, supply and irrigation network generally comprises [ANBT 1999]:

- two major dams: Beni-Haroun and Boussiaba a capacity of 960 and 120 hm<sup>3</sup> respectively;
- three storage dams: Wadi Athemenia 35 hm<sup>3</sup>, Koudiat Medouar 62 hm<sup>3</sup>, and Ourkis 65 hm<sup>3</sup>;
- three stations of raw water pumping capacity of the largest of which is that of Beni-Haroun with a capacity of 180 MW displacing 23 m<sup>3</sup>·s<sup>-1</sup> at a height of 800 m;
- 200 km of pipes of large diameter raw water transfer tunnel, 7 km;
- six lanes of drinking water consisting of 3 treatment stations, 460 km of aqueducts, 25 reservoirs and 15 pumping stations;
- four irrigation schemes with a total area of approximately 42 000 ha.

In addition to the volume regulated by the Beni-Haroun dam (435 hm<sup>3</sup>·y<sup>-1</sup>), the system will complete, in a second step, by connecting the dam Boussiaba (Boussiaba wadi, a tributary of Kebir), providing an additional volume 69 hm<sup>3</sup>·y<sup>-1</sup>, bringing the total to 504 hm<sup>3</sup>·y<sup>-1</sup> transfer to wilayates from within.

Resources distribution has been established based on the needs of communities and industries of the top principal 5 wilayas concerned (Mila, Constantine, Oum-El-Bouaghi, Batna and Khencela), evaluated for 2030 [ANBT 1999; 2000]. The balance available (about half the total regularized) will be used for irrigation of the four perimeters: Teleghma, Chemora, Batna, Ain-Touta, Remila, Touffana and together covering nearly 41 030 ha. The drinking water supply of a part of the Jijel (urban centers of the Daira El Milia) will be provided directly from Boussiaba dam (Fig. 2). The main components of the hydraulic transfer are illustrated by the schematic diagram in Figure 2.

## RESULTS AND DISCUSSION

### SOCIO-ECONOMIC IMPACTS

The advantage is bringing greater integration of large scale irrigation and industry services designed by the Algerian state. The transition from dry farming to irrigation will sufficiently improve yields and make them safer crops. For farmers whose lands were flooded by the dams retained the

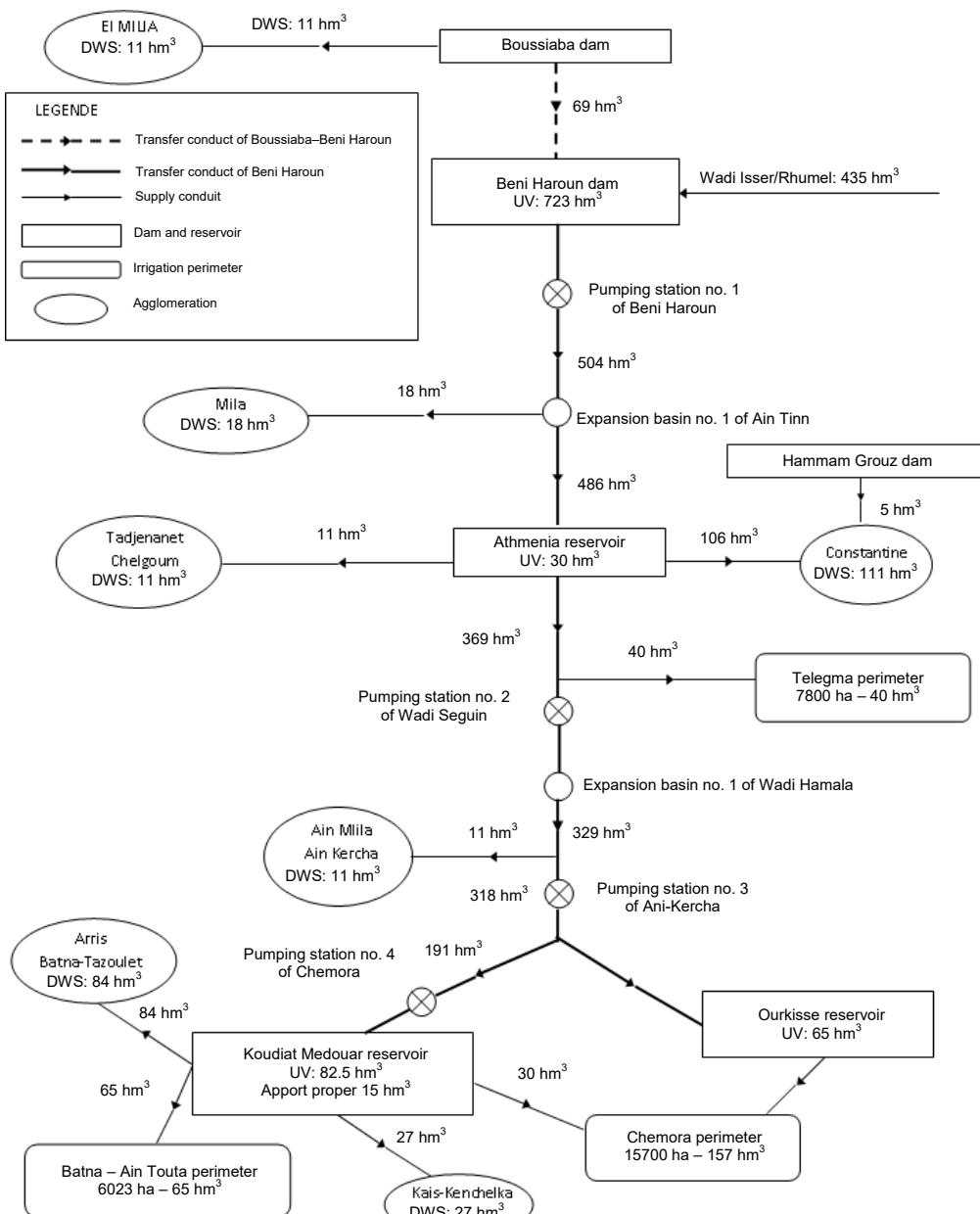


Fig. 2. Functional scheme of resource allocation and transfer of Beni-Haroun; DWS = drinking water supply, UV = useful volume; source: own elaboration

hydraulic transfer of Beni-Haroun is even more deplorable as they are forced to leave their land and their habitat. Their future is so closely defined by the authorities who choose more or less successfully the places and manner of resettlement [BETHEMONT 1986].

If the dam Assaouan example [BAKRE *et al.* 1980], we observe a strong discrepancy between the policies of the Sudanese and the Egyptians for the resettlement of Nubians under the two countries.

Last census operation of 1998 has numbered 2 056 000 inhabitants, divided into 90 communes and 6 Wilayas. Fifty-six (56) municipalities are fully included in the basin and thirty-four (34) partially. Alone, Wilaya of Constantine (462 187 inhabitants) represents 22.5% of the basin's total population.

The drinking water supply in 2030 of the study area is estimated at  $300 \text{ hm}^3 \cdot \text{year}^{-1}$  [MAROUF 2012] transfer from Beni-Haroun in Wilayas presented above to support drinking water for residents. These massive deficits will transfer water needs of about 4 mln inhabitants in 2030. The first tranche of development on water supply of water from the two provinces of Mila and Constantine is already operational from 2006. Only the first instalment, the affected population, spread across 19 cities will reach more than 2 mln by the year 2030. It is envisaged that an annual volume is  $121.2 \text{ hm}^3$  [ANBT 1999].

The second corridor that is almost completed feeds eight cities in the wilayas of Batna and Khencela, through the transfer by back-flow of Beni-Haroun to Koudiat Medouar reservoir, nearly  $60 \text{ Mm}^3 \cdot \text{year}^{-1}$  will provide

1.5 mln inhabitants in 2030. The 3rd instalment of the transfer that feeds Oum-El-Bouaghi, Ain Mlila, Ain Fakroun and Ain Beida from the dam reservoir Ourkis by way of gravity supply and discharge of dam water Beni-Haroun and with an annual volume about  $37 \text{ hm}^3$  [ANBT 2008].

The industry in the basin of Kebir Rhumel is concentrated around major cities (Constantine, Chelgoum Laid, Khroub, Hamma Bouziane, Mila and Didouche Mourade) notably the excavators and cranes complex of Ain Smara, the detergents ENAD-SODER Company of Chelghoum Laid, the Motors-Tractors complex of El Khroub, the Cement factory of Hamma Bouziane, the ceramic tiled company of Mila, and Soda drinks, Syrup of Didouche Mourad [ABH-Constantine 1999; 2004] etc. (see Fig. 3).

The industry in the Kebir-Rhumel basin considered a very important sector in improving the lifestyle of the inhabitants. This industry consumes a lot of water that is thrown dirty, loaded with chemicals, pesticides, heavy metals, hydrocarbons and inorganic, etc. If they are not treated in sewage treatment stations, they will lead to physical and chemical pollution of the environment. In the industrial world, it remains difficult to properly manage hazardous waste and treat the contaminated medium rivers,

aquifers and dams, as it is the case of wadis Rhumel and Enndja waters that will be stored with these different rejections in reservoir level Beni-Haroun dam.

It is always recommended that the distance between points in restoration and reuse must be at least 8 km (distance travelled in one day flow at low water by a lowland river) i.e. a minimum of self-purification [RODIER 1996].

Industrial wastewater characteristics in Kebir-Rhumel (canneries, oil mills and others) can vary according to their origins, industrial discharges on the quality of water depending on their affinity with oxygen, the solid quantity in suspension and their content of organic and inorganic substances, organic matter can promote growth of microbial populations, decrease of oxygen levels and therefore, promote biomathematics, the rate of this process increases with warmer temperatures that favour a biological production and decreases during winter.

The summary of water requirements for industry in the pelvis is shown in the table below:

We note water volumes inadequacy intended for industry, in particular in the Wilaya of Constantine, also the recycled volume in various agglomerations is worrying and represents only 30% of industrial needs total volume (Tab. 1).

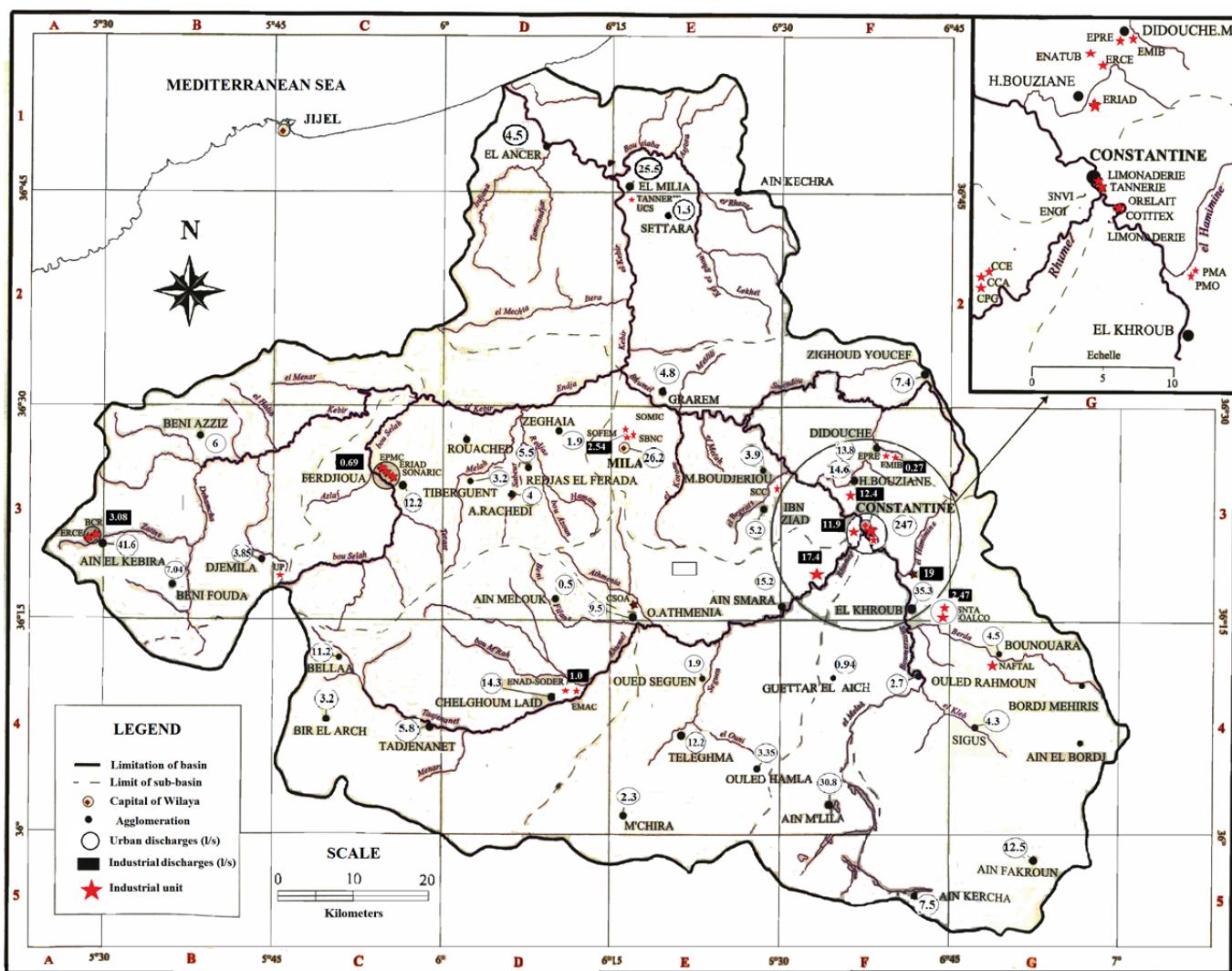


Fig. 3. Map of urban and industrial discharges; source: ABH-Constantine [1999; 2004]

**Table 1.** Industrial needs in the Kebir Rhumel basin

Sub-basins	Total water need ( $m^3 \cdot d^{-1}$ )	Total industrial volume ( $M^3 \cdot d^{-1}$ )	Total recycled volume ( $m^3 \cdot d^{-1}$ )
1004-1007	14 077	10 643	525
1002-1003	847	838	395
1001-1005	387	322	80

Source ABH-Constantine [1999; 2004].

Agriculture in Kebir Rhumel basin is mixed, traditional type (gravity), and modern irrigation (by spray channels) by culture type. Cereals and vegetables are the main activities of irrigated areas. A positive socioeconomic impact of hydraulic transfer of Beni-Haroun on the current and future development of irrigation. The waters of Beni-Haroun dam used to irrigate existing farmland with an area of approximately 42 000 ha may be an extension given the enormous existing potential. The creation of these irrigated areas could strengthen the dominant traditions of local residents by the arboriculture [ABH-Constantine 1999; 2004].

We can qualify this advantage as very significant. It will be difficult to estimate the exact number of job positions that will provide the realization of Beni-Haroun transfer. The creation of new farmland probably fathomed the creation of new jobs, thereby strengthening the agricultural in several regions of basin. To the region East, the transfer is from the Ourkis reservoir at Oum-El-Bouaghi. It will regulate the water supply for irrigation of a perimeter of 15 000 ha in the Chemora region and also of Touffana-Remila perimeter (11 000 ha) allocated 2 000 ha in Touffana area and 9 000 ha in Remila plain.

Koudiat-Medouar reservoir, also ensure the irrigation perimeter of 6 000 ha (corridor Batna-Ain Toudra). This reservoir will assure probably additional water to irrigation perimeter.

The irrigation projects powered by the hydraulic transfer of Beni-Haroun dam are as follows:

**1. Teleghma perimeter:** (8 000 ha) extends along the valleys of the high Rhumel basin and its tributary the Seguin River, in an area between the centers of Ouled Hamla South and North Wadi Seguin. This semi-arid zone of northern fringe of the High Plains (around 400 mm of rain per year), mainly devoted to grain dry soil contains clay and silt that are suitable for irrigation.

Plain of Teleghma-Ouled Hamla already experienced the benefits of agricultural intensification through the exploitation of groundwater by several hundred wells with pump.

However, given the importance of water deficit and drawdown of the groundwater (effect of exploitation), an external supply of water is necessary. The area is currently under review by the Algerian Company (Hydro-Project-East) for its equipment and irrigation from Wadi Athmania reservoir.

**2. Chemora perimeter:** (15 000 ha), located between the wilaya of Oum-El-Bouaghi and Batna is located in a heavily marked by the endorheic in the heart of the High Plains where water deficit is greater than Teleghma (Fig. 4).

The wadi Chemora which rises on the slopes of the Aures flows into a narrow corridor between djebels Bou Arif and Fedjoudj to reach the plains of North Boulhilet.

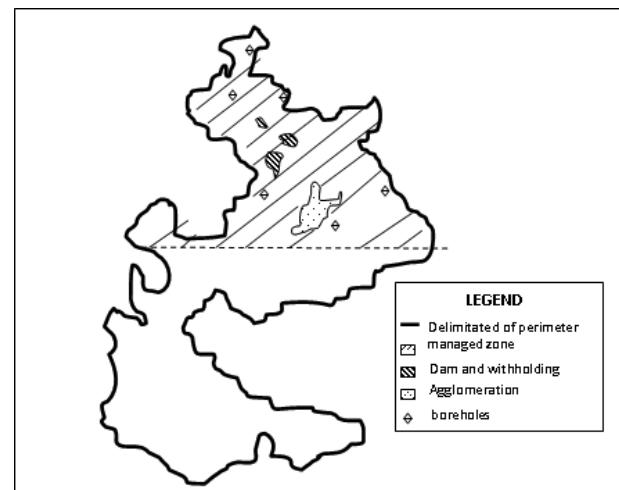


Fig. 4. Delimitating of irrigation perimeter of Chemora;  
source: own elaboration

This area has experienced a traditional irrigation type based on sharing system, using a spreading of flood. It allowed, by arranging seds (bunds) and irrigation canals to enjoy the land of flood waters of the Chemora River. Today, the Wadi is captured by the upstream Koudiat Medaour dam.

The project perimeter should be irrigated from Beni-Haroun water passing through Ourkis reservoir.

**3. Touffana Remila perimeter:** (11 000 ha) is divided between 2 000 ha in area Touffana (Ouled Fadhel) and chosen from 9 000 ha to 21 000 ha of lowland soils Remila having already been the subject of agro-pedological studies in 1971 and 1973 [ANBT 2003].

The selection of land suitable for irrigation takes into account two main constraints to development in the region: salinity and soil depth.

At the request of the Agency of Irrigation and Drainage (Fr. Agence d'Irrigation et Drainage – AGID), equipment of this perimeter is being studied by Energoprojekt (Fig. 5). The old irrigation area of Foum El Gueiss (3 200 ha), aborted due to siltation of the dam is incorporated in project perimeter.

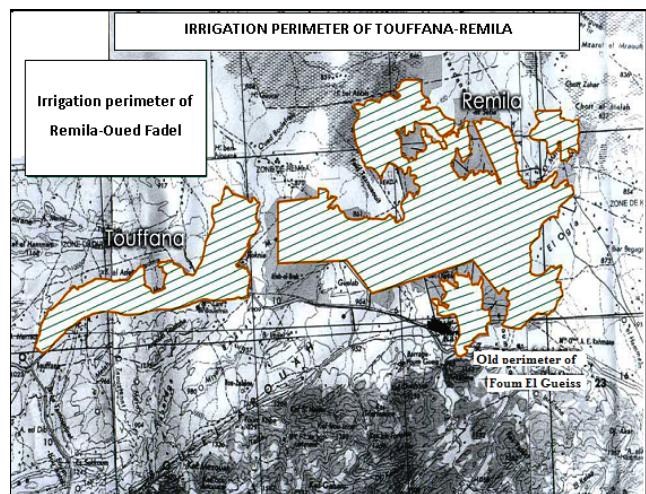


Fig. 5. Irrigation perimeter of Touffana-Remila;  
source: own elaboration

Water resources would be allocated to the area, most likely transported from the Koudiat-Medaour dam.

The contribution of irrigation water showed its effects on the agricultural development of these vast areas of the Piedmont of the Aures (NFARD projects – the National Fund for Agricultural and Rural Development – General Grant and Agricultural). The means of large hydraulic are likely to transform the landscape of nudity and improve the socioeconomic situation of the rural population.

**4. Batna-Ain Touda perimeter** (6 000 ha): extends between Batna and Ain Touda in a long corridor North-East-South-West, between the mountains of Bellezma and the chain of the Aures. This area is object of future studies. Water resources allocated to it are not yet strictly defined. The characteristics of the area to be irrigated were mentioned in the Table 2.

**Table 2.** Irrigation perimeter characteristics of Beni-Haroun dam

Irrigation perimeter	Area equipped (ha)	Allotment volume ( $\text{hm}^3 \cdot \text{year}^{-1}$ )
Teleghma	7 079	69.5
Remila – Wadi Fadel	10 849	86.3
Batna – Ain Touda	6 171	45.8
Chemora	16 940	90.4
Total	41 039	292.0

Source ANBT [2012].

Note that, the consequences of increased agricultural activity that develops in the area is growing concern because of the intensive use of fertilizers, chemical or organic, and excessive use of pesticides (insecticide, herbicide) and fungicides. Agriculture, livestock and poultry are responsible for the rejection of many organic and inorganic pollutants in surface water and groundwater in the region.

These contaminants include both sediment from erosion of agricultural land, the banks and beds of rivers, phosphorus compounds or nitrogen, from animal wastes and commercial fertilizers, especially nitrates ( $\text{NO}_3^-$ ) and phytosanitary products, which were not decomposed will feed algae which multiply and consume all the oxygen. Animal wastes are low in oxygen, rich in nitrogen and phosphorus and often contain pathogens. Residues from fertilizers are retained by the soil but can contaminate waterways by runoff from rainfall or irrigation and groundwater through leaching.

#### IMPACTS ON WATER QUALITY AND NATURAL ENVIRONMENT

The socio-environmental greatest concern today in the Kebir-Rhumel basin are eutrophication of Beni-Haroun dam, the proliferation of aquatic plants and the risk of the prevalence of waterborne diseases due to the uncontrolled release of domestic sewage and industrial especially in peripheral areas of Beni-Haroun dam [ANBT 2003]. These adverse consequences are the result of disruption of biophysical environment of the basin, following the flow regulation of wadis Rhumel and Enndja. Consequential impacts on the great structures not only concern the morphology of beds but also water quality and hydrobiotic

systems [PEIRY 1990]. They are likely to affect large areas sometimes very far from works that may be implicated. Due to space distancing and spreading over time, they were not clearly detected during changes caused by human action [GOUDIE 1986]. The construction of large dam reservoir, if the reservoir of Beni-Haroun as the first effect, a radical change in the middle. In deep areas of the reservoir, the water accumulated tends to a thermal stratification with warmer upper layer in summer and colder in winter than the lower layer. In the latter case, vertical density currents can push and reverse stratification or abolish it, and the water temperature becomes uniform. Stratification of the oxygen content undergoes a reduction in depth going up to total deoxygenating; while in the area exposed to air enriched this content. It is naturally high in water courses which the vortices promote mixing by stirring. In shallow areas, some soluble phosphates develop biological activity as to lead to an excess of organic food: this is eutrophication. Algae-cluttered lake and putrescible waste generating hydrogen sulphide becomes repulsive. The main expected impacts of the project are linked to the modification of the aquatic environment, which will affect the production of aquatic fauna and water quality of rivers. The accumulation of pollutants in the reservoir promotes the degradation of water quality in the reservoir below the dam, even the pollution risk by heavy metals (Cu, Cr, Zn etc.). In recent years [MERZOUGHI *et al.* 2019], periodic water quality analysis has been of increasing interest in many regions because water is a precious and essential natural resource for multiple uses (domestic, industrial and agricultural).

Parameter control pollution indicators produced by the ANRH of Constantine during a period of ten years in the Kebir-Rhumel basin shows that all surface water in the basin has acceptable concentrations of nitrate ( $\text{NO}_3^-$ ) but exceed  $25 \text{ mg} \cdot \text{dm}^{-3}$  in Grarem station. With regard to nitrite ( $\text{NO}_2^-$ ), Grarem, Menia and Ain Smara stations far exceed  $1 \text{ mg} \cdot \text{dm}^{-3}$  (excessive pollution).

Turbidity and phosphates show poor water quality in the different gauging stations studied. Water concentrations of sulphates ( $\text{SO}_4^{2-}$ ) are very remarkable; it is of the order of  $300 \text{ mg} \cdot \text{dm}^{-3}$ . The indicators parameters values of pollution such as, the dissolved oxygen,  $\text{BOD}_5$  and COD confirms the poor water quality in the rivers of basin, Ain Smara and Menia stations in the Constantine region show strong contamination by pollutants where industrial activity is highly intensive.

Some analyses of heavy metals elaborated by Constantine ANRH show dangerous levels, the Wadi Kebir-Rhumel waters of reached the Beni-Haroun dam with copper concentrations about  $0.012 \text{ mg} \cdot \text{dm}^{-3}$ .

Turbidity and suspended solids concentrations are higher in the dam. Despite the waters average quality of Beni-Haroun dam, effectuated analyses in 2006 on some physicochemical and bacteriological parameters ( $\text{NO}_3^-$ ,  $\text{PO}_4^{2-}$ ,  $\text{BOD}_5$ , COD, dissolved  $\text{O}_2$ , saturated  $\text{O}_2$ , etc.) indicate chemical and microbiological contamination of waters of this immense restraint [MAROUF 2012], which promotes algae growth and accelerate eutrophication (a very dark green colour is observed in the dam waters, especially near the dam seawall).

The Wadi Rhumel is currently used as a receiving environment of a large proportion of liquid discharges from urban group of neighbouring Wilayas [ANBT 2003]. Related to the ecological consequences of water pollution, especially during low water, is added to the risk of a severe deterioration in public health. Indeed, waters contamination of river and thus groundwater and food products (especially during cultivation and harvesting) by the different fecal germs increase the exploitation risk to infectious diseases (cholera, dysentery, diarrheal diseases, hepatitis, etc.). These diseases can affect, in particular, people closest to the Beni-Haroun dam, as the case with many diseases that have been observed in Egypt (Nile Delta), the banks of the Zambezi and the China [BETHEMONT 2002].

The construction of this dam will certainly change activities practiced by some citizens. These new facilities will bring citizens, especially farmers to change their practice of certain activities on the main river and at the dam periphery. Some agglomerations devices the dam requires to improve their waste disposal systems for wastewater trying to reject these waters preferably downstream of Beni-Haroun dam or installing different treatment stations necessary, using different modes of treatment recommended in this region. Measures have been taken into consideration by the National Agency for Dams and Transfers (ANBT) to relocate, quantify and characterize releases of the peripheral region of the reservoir and secure the key work of the hydraulic system. The delay in the studies developed and construction of wastewater treatment plants to quantify, monitor and treat wastewater in agglomerations concerned resulted in a real environmental problem on the dam waters and the natural environment. Environmental monitoring throughout the implementation and operation of the hydraulic transfer is necessary, the filling of dam, stability of the dam wall, leaks in the dam and the hydraulic system, to ensure the implementation of mitigation measures. The construction works of the great hydraulic transfer will result in significant economic benefits in the country. The cost of the hydraulic transfer is approximately 3.9 bln USD, expenditure on this project will be to maintain or create jobs in eastern Algeria. The majority of workforce (manpower) could come from this region.

## IMPACTS ON SEDIMENT TRANSPORT

Hydraulic works affect not only abundance and the rhythm of discharge but as well, hence affecting the dynamics of sediment transports. Big reservoirs and dams trap the basic loads, gravel and rollers as well as a part of sand silt. All this will necessitate a regular downstream driving out of reservoirs waters. Hydrological changes will affect the conditioning and moving of the basic load. Sedimentary transits will lead to geomorphologic changes that will have an impact on the river bed.

The blocking of the deep change induced by the rupture of the sedimentary continuums consequently to the construction of dams is a classic thing in the geomorphology literature and its impact on the rivers [KONDOLF 1995; PETTS 1984; WILLIAMS, WOLMAN 1984]. What is certain,

however, is that hydraulic works have even led to hindering the handling [VIVIAN, PUPIER 1996].

Beni-Haroun dam case has been designed with only two half melts valves situated at the level of the dead volume estimated at a dimension of 140 m that will not to minimize sediment transport in the reservoir and to evacuate them by the current density in the early years of their operation, the vase located below the dead volume, while opening of the bottom outlet and during large floods is still blocked, compacted and consolidated at the bottom of the reservoir.

In zones of high sediment production, where the Beni-Haroun dam probably receives up to  $22 \text{ Mm}^3 \cdot \text{y}^{-1}$  [MAROUF, REMINI 2011]. Concentration and flow evolution during the flood period in the basin of studies gives some indications as to the functioning of the hydro-sedimentary water stream the El-Ancer station downstream the basin gives the most important flow  $1000 \text{ m}^3 \cdot \text{s}^{-1}$ , the highest concentration of suspended sediment SSCmax ( $100 \text{ g} \cdot \text{dm}^{-3}$ ). The hysteresis analysis of the concentration-flow parameters shows the predominance of the sedimentary in the river bed.

These localized lithological formations in the basin are continuously subjected to strong erosion. The calculation of specific annual erosion over the entire study period revealed the years that have contributed strongly to rapid siltation of Beni-Haroun dam. 1984 and 1990 present a maximum specific erosion value that exceeds  $2200 \text{ Mg km}^{-2} \cdot \text{y}^{-1}$  [MAROUF 2012].

Sediments decantation case has also demonstrated in many countries, to wit Salvador where the sediments volume recorded was about  $13 \text{ Mm}^3$  ( $0.37 \text{ Mm}^3 \cdot \text{y}^{-1}$ ) between the years 190 and 1965 and in Mairienne the water reserve of Sain-Martia reservoir where the capacity shifted from  $0.371$  to  $0.21 \text{ Mm}^3 \cdot \text{y}^{-1}$  between 1974 and 1986 (hence about  $15\,000 \text{ m}^3 \cdot \text{y}^{-1}$  of depots), This is despite the annual hunts aimed at limiting sedimentation; on the French-Swiss Rhone River,  $0.35$  to  $1.00 \text{ Mm}^3 \cdot \text{y}^{-1}$  were formed the total amount coming from the Arve [BRUSCHIN 1987]. In Algeria the sediment quantity in 98 dams has been evaluated to  $650 \text{ Mm}^3$  in the year 2000 that is a rate of filing of 14.5% [REMINI 1999].

To reduce the problems of sedimentation and loss of useful capacities of the dam, periodic evacuations are necessary; transits are load during times of emptying for auscultation and maintain dams. The role of these hunts is to evacuate the deposits retained to maintain their storage capacity and release the bottom valves and hydrants. We take advantage of periods of high water levels to achieve them.

In order to limit problems related to sedimentation and waste of useful capacities of the dam, periodical evacuations are necessary, the load transits being done at the drain periods to assure the dams maintenance. The role of these hunts is to evacuate the deposits retained to maintain their storage capacity and release the bottom valves and hydrants. We take advantage of periods of high water levels to achieve them.

Flushing and draining of dams frequently have strong consequences on the river environment. Water quality is

highly altered, fine tuning of deposition also contributes to transit brutal in the middle of broad amounts of pollutants (pesticides, heavy metals, ammonia) and a sharp decrease in dissolved oxygen content of water. It also appears that the exported materials for participating in blockage of funds and contribute to a “cementing” the alluvial substrate damaging to biological cycles, exchanges water/river and mobility of bed sediments. Even for the case of structures in the dam, this is structures of about 200 m high, equipped with a weir free flowing and can be eroded due to flows cavitation [BOUVARD 2004]. This case was observed in the dam Kerum in Iran, the curvature of weir has caused erosion due to cavitation which eventually completely eliminates the concrete lining of the profile to the rock, a considerable distance. This can also touch the bottom outlets. Note that the shielding of the drain openings in the dam of Serre-Ponçon had been perforated by cavitation, a triangular area of  $20 \times 30$  cm [BOUVARD 2004]. The volume of a pit as a result of this phenomenon also reached  $150 \text{ m}^3 \cdot \text{s}^{-1}$ . Same as the transport of raw water dam with a water supply network of 200 km and three pumping stations will compromise the malfunction of transportation and treatment.

## MORPHOLOGICAL AND TECTONIC IMPACTS

Morphological impacts will accord the dams nature, whether those are reservoirs-dams or water streams dams. In general, sediments are trapped when coming upstream and give decanted water downstream. There is then a filling progressive upstream at a variable rhythm according to the morphology of basins and the erosive dynamics. In central Europe for instance, the filling of water reserves is about 0.51% however in China the Sanmenxia dam, achieved in 1960 has been transformed onto a simple basin of decantation in 1964 [BOUVARD 2004; MAROUF 2012]. Downstream water streams coming from water reserves will provoke incisions in hard rocks as there is an exceeding capacity in general erosion phenomena (moving from a rectilinear stream to a sinuous area). The destabilization phenomenon will moreover have a larger dimension when situated in a zone where there are movable rocks.

In North Africa the Algerian case, the transports and erosion phenomenon of sediments is largely spread and threat the potentialities of both soil and water. The erosion rate in the North African countries is one of the highest in the world. Works underway of DEMMAK [1982] about erosion and sediment transport have showed that erosion has reached the level of  $2\,000 \text{ t} \cdot \text{km}^{-2} \cdot \text{y}^{-1}$  on most of watersheds. The carrying of sediments that reached Beni-Haroun dam was about  $2\,600 \text{ Mg} \cdot \text{km}^{-2}$  [MAROUF, REMINI 2011].

The Algerian hydraulic infrastructures, mainly the dams, are at a high risk of silting and sedimentation. A continual anti-erosive struggle is then necessary in order to preserve and protect the lands upstream. The flow pattern is most affected; the transit of the water releases on sections of non-established waterways amplifies the undermining of the banks and the undermining of the bed, creating important deposits with the downstream [TOUAI-BIA 2010].

With the impacts related to the transfer of sediments, can be added various traumas; landslide in the reservoir like the case of Italian Vajont, rupture of works established on fields of faults. The case of Malpasset in France will remain exemplary from its dramatic consequences. Border-line case of weight of a reservoir established in unstable medium can cause a seismic movement: the filling of the Lake Mead on Colorado in 1935 was followed by several rather full seismic movements. It was in the same way for the Kariba dam established on the field of rock faults and was followed in 1960 of an earth tremor reaching 4 on the Richter scale.

The geomorphology of area of the project of the transfer is related to a complex tectonic history. A particularly important tectonic phase developed in lower Miocene. According to the observations and the updated recordings in December 1997, the site of the Beni-Haroun dam, although located at the limit of two geomorphologic provinces seems to present seismicity less important than neighbouring areas such as the zone of Constantine and Babors. The area of Beni-Haroun is located in a classified seismic area, according to Bochel as being able to undergo an intensity of VI with VII. This area is bordered in the North-West and in South-East by two more active zones seismically in intensity higher than VIII. The earthquake, indexed as the most important in a radius of 50 km around the site, is that of October 27th, 1985 magnitude 5.9 of Richter scale [ANBT 2002] and whose epicenter is located at North-East of the town of Constantine with approximately 40 km of Beni-Haroun dam. The tectonic structures dimensioning for the site are situated in the basin of Constantine which is limited to the faults which border the solid mass. By displacement of these earthquakes until the zone or structure nearest of the site, one can consider that an earthquake magnitude 5.9 can have its epicenter with 20 km of the site and that an earthquake magnitude 4.6 can have its epicenter with 1 km of the site [ANBT 2002]. The effects of installation of dam like the case of Beni-Haroun on carsick foundations presents an immutable effect on the evolution of the hydrological and climatic mode of the area.

During operation of Beni-Haroun dam, the responsible of water sector and (ANBT) decided to temporarily stop pumping starting from the great pumping station of Douar el Bidi following escapes of water considered to be “important” recorded on the level of the tunnel of transfer of water of the Beni-Haroun dam located at Djebel Lkehah, Wilaya of Mila.

The transfer tunnel is used to convey waters of the Beni-Haroun dam to the Wadi Athmania dam reservoir. Significant amounts of water were lost. The estimation of the water loss, due to this leakage, according to ANBT, is of the order of 35% of the pumped volume is of the order of  $12.5 \text{ m}^3 \cdot \text{s}^{-1}$ . This temporary stopping of pumping lasted a few months during which repairs were completed by the Italian firm having realized the tunnel.

Specialists in hydraulics do not exclude the possibility of the relationship between seismic activity recorded in the region during this period and the quake magnitude (3.3 degrees) recorded before the onset of leakage.

According ANBT, there are problems in the foundations of the structure and water infiltration estimated at  $1.2 \text{ m}^3 \cdot \text{s}^{-1}$ , preventing services operation of the dam to fill and operate the dam an optimal way. Infiltration problems may pose a threat to the population and the ecology of the region, disaster.

The disadvantage of the pumping station prototype manufactured by a French company was noticed in the spare parts are non-existent and the non-mastery of modern technology operating large resorts. In case of failure, in this station may paralyze the whole system of Beni-Haroun and deprive citizens consumers. Less leakage with pumping pressure of 8 MPa, could cause a huge explosion.

The project consists of several lots which transfers to the five wilayas concerned should secure much of the East region in drinking water (nearly 4 mln inhabitants spread over the territory of the six wilayas).

The completion of this dam has an influence on the aquifer in the region, according to data collected by the Hydric Water National Agency (Fr. Agence Nationale des ressources hydrauliques – ANRH), Direction of Water Resources of Wilaya (Fr. Direction des Ressources en eau de la Wilaya – DRE) and Hydrographic Basin Agency of Constantine (Fr. Agence des bassins hydrographiques de Constantine – ABH). An analysis of ratings and drilling flow operated was conducted in three wilayas (Constantine, Oum-El-Bouaghi Mila upstream and downstream of Jijel dam). Observed data (Tab. 3) show higher rates of drilling in the Wilayas upstream dam Beni-Haroun by comparing the operation of water wells in the two years (1998 and 2004). Groundwater will be recharged and more especially in the area around the bowl. Data analysis shows the depression of the ground water upstream of the Beni-Haroun dam, and while downstream the raising of that level will induce a rise in groundwater.

**Table 3.** Flow in state boreholes in the Kebir-Rhumel basin

City (Wilaya)	1998 year		2004 year	
	$Q_n$	$Q_{exp}$	$Q_n$	$Q_{exp}$
	$\text{dm}^3 \cdot \text{s}^{-1}$			
Constantine	1 494	1 010	2 310	1 955
Mila	960	873	1 767	1 129
Oum-El-Bouaghi	740	710	1 027	927
Jijel	960	873	1 267	648

Explanation:  $Q_n$  = nominal flow,  $Q_{exp}$  = exploited flow.

Source: own elaboration based on data of: Hydric Water National Agency (ANRH), Direction of water Resources of Wilaya (DRE) and Hydrographic Basin Agency (ABH).

The only Wilaya located downstream of the dam site shows a lowering of its groundwater and this is due to the drop in power of the latter by the implementation of the dam on the major bed of the Wadi Kebir. The decrease in the level of groundwater in the region of Jijel north-Kebir-Rhumel basin is remarkable even though it is the most rainy region of the basin (average rainfall is about 1000 mm).

Going far to the North, downstream the dam, the deficit of sediment supply also results in a destabilization of the coast (back of the littoral cordon). This phenomenon is particularly serious in the case of the Akosombo structure

that traps all the sandy sediment supply, until quite important in the Volta structure. These contributions were originally deltaic and lagoon al training fairly stable and their separation was followed by a resumption of erosion marked by a decline in the littoral cordon of 12 m per year. The lagoon has almost disappeared and the small town of Keta, East of the delta is being destroyed rapidly [ROSSI, BILIVI 1995]. The evolution of the Egyptian shores is no less critical: as a result of sediment trapping in Lake Nasser, it was necessary to protect the coastline of the delta by riprap, further East, littoral currents attack the littoral cordon of Bradwil and cause a decline in beaches of up to  $3 \text{ m} \cdot \text{year}^{-1}$  in the El-Arish region where seaside stations are threatened. In the case of our study, the coast North of the basin also has a decline due to the establishment of the Beni-Haroun, Hammam-Grouz, Wadi Athmania and Boussiaba dams. Translation lowest sediment along the coast, this can be beneficial to the Jijel port avoiding filling difficult to fight and also a decrease in nutrient contributions to plankton, this can have a negative effect on fish production of the region.

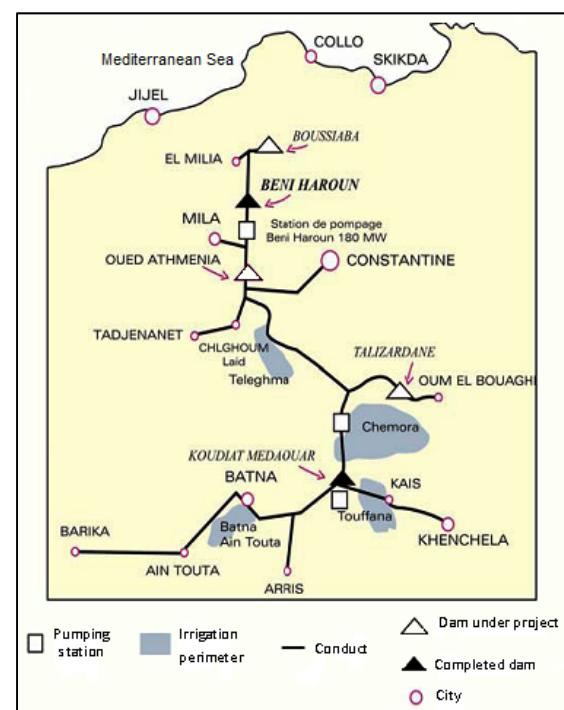


Fig. 6. Regional schema of Beni-Haroun transfer;  
source: ANBT [2002]

## DEPOLUTION STRATEGIES

The purpose of the depollution project is to reduce pollutant flows toward Lake Beni-Haroun to not jeopardize future uses, particularly drinking water production, which is the main issue of this work.

Impacts of pollutant fluxes on the dam reservoir are noticeable through several ways: contribution to the dam siltation, contribution of biodegradable organic matter decreases oxygen rate in water and fermentation and dystrophy as well as appearance of toxic compounds. pH related to photosynthesis is at high values during the day. If, in

addition, temperatures are high and ammonia ( $\text{NH}_4^+$ ) contents are high, gaseous ammonia ( $\text{NH}_3$ ) that is very toxic to fish occurs due to environment asphyxiation. During the day, plants produce lot of oxygen through photosynthesis and during the night, they consume few of it through respiration. If the amount of plants in the reservoir is very important, in the early morning, all the oxygen in the water may be consumed. Fish and some aquatic insects can die due to asphyxiation. Nitrogenous materials can compromise piscicultural life, increase potabilization costs and contribute to eutrophication. Phosphorus substances contribution is widely responsible for environment eutrophication with excessive production of algae and organic matter, potabilization obligation and risks of asphyxiation and fermentation.

These impacts are even more significant during summer (almost no flow in all thalweg and watercourses) in case of the semi-arid climate. Therefore, it will be necessary to reduce pollutant emissions during these periods of environmental fragility. The challenge then is to limit these impacts by implementing a depollution schedule that involves collection and treatment of urban effluents, particularly the peripheral areas of the reservoir dam.

Most purification processes provide very easily effective treatment of organic matter and suspended solids, while treatment of nitrogen and phosphorus requires implementation of other more complex processes.

The environmental study will specify the impacts of residual flows and discharges levels necessary for each agglomeration.

Indeed, pollutant flows pass through different watercourses and transit periods consider self-purification phenomena before discharge into the lake.

Therefore, at present, the ANBT will aim preventively to limit the contribution of agglomerations in the reservoir dam peripheral areas while proposing feasible and realistic solutions [ANBT 2003], but delays in these works during the dam operation and commissioning for drinking water supply has caused poor and uncontrolled water quality in the dams reservoirs.

In these situations, complementary solutions for raw water treatment are envisaged to reduce residual inputs in the dam reservoir and to limit the treatment levels on the purification works and consequently on the investment costs as well as operations of these stations.

The diversion of effluents downstream of the dam is a radical solution, requiring major connection work (more than a dozen kilometres) where they are treated in treatment unit [ANBT 2003]. This solution would be conceivable for Mila, Garem and Sidi-Merouane agglomerations, which constitute 80% of the population surrounding the reservoir dam.

Reuse of water after treatment is a national priority in the context of the country's shortage. This alternative of recovery was considered for some treated effluents by treatment units of Constantine and Chelgoum-Laid.

It should also be remembered that reuse from raw effluents is a common practice in the study area. Farmers drift water on the lands from collectors or watercourses. For Constantine and Chelgoum-Laid regions treatment

project case, farmers have noted that these samples before reaching the treatment station are significant and lead to an important and detrimental decrease of the incoming charges in the stations, operating at low load. In the future, these practices shall be regulated both for health issues and to ensure proper functioning of the collection and purification works.

The quality level required for agricultural valorisation of wastewater can be defined by referring to recommendations stated by WHO [1989].

## CONCLUSIONS

When Beni-Haroun dam hydraulic system is put into operation, part of eastern Algeria area will be in structured around a powerful hydraulic system, a factor of regional integration in favour of semi-arid regions. To value and preserve these very expensive developments, the "sustainable" and integrated approach is required.

The integration of sociological and environmental concerns in dams design is a recent phenomenon. It is considered in the impact study, a procedure in which the project of the dam study is accompanied by an investigation to assess project impacts on the natural environment and the socio-economic development. For this two main reasons, firstly an evolution of social behaviour of inhabitants vis-à-vis the protection of the environment and other strict regulations on water and pollution. The Beni-Haroun transfer seeks intended to transfer an annual water volume of  $504 \text{ hm}^3 \cdot \text{year}^{-1}$  ( $435 \text{ hm}^3$  whose own volume and  $69 \text{ hm}^3$  transfer of Boussiaba dam). These resources are mobilized by the Beni-Haroun dam to the six provinces of Batna, Khencela, Mila, Oum-El-Bougah, Constantine and Jijel (Mila Region) in order to satisfy their drinking water needs and industry in 2030. The various advantages of the Beni-Haroun dam over other dams, given its high capacity, it could not only fill the water deficit of zones eastern Algeria (about 4 mln inhabitants) long term but also help irrigate about 42 000 ha of land with a flow discharge of  $292 \text{ hm}^3 \cdot \text{year}^{-1}$ .

This project represents a major investment in the region. It should allow the development of intensive agriculture (market garden culture, intensive fodder, industrial cultures) in the high plains far devoted to dry cereal with low yields.

In industry, urban discharges and industrial discharges shall be separated by installing purification plants adapted to the rejections nature and by controlling the rejections with the regular means.

Urban and industrial discharges in the major conurbations of the Kebir-Rhumel catchment area and in particular in the peripheral areas of the Beni-Haroun dam containment are worrying and poorly controlled upstream, a schedule to build treatment plants is in progress (WWTP with activated sludge system) is implemented. It will be necessary to wait for its full realization to notice the effluents depollution rate improvement.

Self-measurement is a very effective mean, the water requirements for irrigation depend mainly on the water

coming from the dam whose water quality is good for irrigation.

For irrigation, when a water table is polluted, it is no longer possible to apply an effective curative action. In this case, only prevention is possible to avoid any potential pollution. Therefore, increased monitoring of contaminated measuring points and other non-analysed well drillings is recommended to assess water quality. Immediate, serious and continuous protection of well drillings with good quality and control of water at the production point shall be implemented.

The interconnection for this hydraulic system dams represents an ambitious option, but does-it require a dynamic management control of the reserves, especially during recurring droughts.

The structuring effect of large dams-reservoirs on a regional scale is indisputable. It should be however, cautious about the repercussions that may result from such macro-structures in terms of both physically, that social and economic.

Impacts study of the hydraulic transfer of Beni-Haroun requires resources and scientists expertise mobilized to predict current evolutions, which requires an effective adaptive strategy.

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## Nadir MAROUF, Boualem REMINI

### Analiza wpływu zapory Beni-Haroun na środowiskowe i społeczno-ekonomiczne problemy w basenie Kébir-Rhumel, Algieria

#### STRESZCZENIE

Wody powierzchniowe na terenie basenu Kébir-Rhumel są niezbędne do zaspokojenia domowych i przemysłowych potrzeb regionu. Rozwój przemysłowy z jego nadmiernym zużyciem wody i substancji chemicznych w procesie produkcji i przetwarzania oraz niezrównoważone stosowanie nawozów w rolnictwie stwarzają poważne zagrożenie dla jakości wody. Większość domowych i przemysłowych ścieków z regionu jest odprowadzana do wód płynących basenu Kébir-Rhumel, powodując ich wzbogacenie w pierwiastki biogenne (fosfor i azot), co skutkuje zwiększoną produkcją pierwotną głównie planktonowych i osiadłych glonów. W wyniku tego pogarsza się jakość wody.

Układ basenu umożliwił zbudowanie największej zapory w Algierii – zapory Beni-Haroun. Ten obiekt infrastruktury wodnej, będący jednym z największych wyzwań Algierii, stał się rzeczywistością. Kompleks wodny Beni-Haroun jest strategicznym i głównym osiągnięciem programu rozwoju zasobów wodnych. Ta ogromna budowla umieszczona w prowincji Mila zaspokaja potrzeby 4 mln mieszkańców wschodniej Algierii i sąsiadujących regionów, które cierpią na brak wody pitnej, szczególnie latem. Ponadto wodą ze zbiornika będzie się nawadniać 42 000 ha na kilku równinach.

Zagadnieniem ostatnio branym pod uwagę podczas projektowania zapór jest integrowanie problemów społecznych i środowiskowych. Te problemy są rozważane na etapie oceny oddziaływania na środowisko, w którym projektowaniu zapory towarzyszy analiza wpływu projektu na środowisko naturalne i rozwój społeczno-gospodarczy.

**Słowa kluczowe:** *basen, Kebir-Rhumel, kwestie społeczno-ekonomiczne, system hydraliczny, transport osadów, zapora Beni-Haroun, zasięg nawodnień*