Larhyss Journal, ISSN 1112-3680, n°63, Sep 2025, pp. 233-283

WATER CAPTURE TECHNIQUES ADAPTED TO CLIMATE CHANGE

REMINI B.

Emeritus Professor, Department of Water Sciences and Environmental Science,
Faculty of Technology,
University Blida 1, Blida 9000, Algeria

reminib@yahoo.fr

Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received January 11, 2025, Received in revised form September 2, 2025, Accepted September 4, 2025

ABSTRACT

This article provides a favorable solution to ensure Algeria's water security in the era of climate change. Four main water sources supply drinking water to the entire Algerian territory. These are sky water, water from transboundary aquifers, water from the Mediterranean Sea, and water from wastewater treatment plants. However, this study focuses only on the first water source, which concerns sky water. So, what is the problem between sky water and climate change? This unregulated climate has a two-season hydrological season; a long dry period with high evaporation, followed by a short-wet period characterized by flash floods. In the northern part of Algeria alone, an average of 100 billion m^3 of precipitation, of which approximately 85.5% of the evaporation volume evaporates into the atmosphere. So, what can be done to reduce the evaporation rate and store more water? Based on a long work of more than 30 years in the oases of the Algerian Sahara, surveys among the peasant populations were carried out. Not to mention the visits we made to the sites of ancestral hydraulic structures. Thanks to this long work, we have highlighted water capture techniques that adapt to climate change by reducing the evaporation rate at the expense of an increase in the volume of stored water. Build as many sand dams as possible, preferably in cascade on the national hydrographic network to ensure a high-water flow. Build underground dams in the depths of the large wadis of the Sahara and in all the wadis of northern Algeria. Build recharge dams on the wadis. Create infiltration basins throughout the national territory.

Keywords: Climate change, Sand dam, Underground dam, Artificial groundwater recharge, Flash floods, Drought, Evaporation.

INTRODUCTION

Climate change has caused an imbalance in the seasons with the appearance of a long period of drought that ends with a short-wet period characterized by flash floods. These variations are so accelerated that the world can no longer adapt to this new unregulated climate while continuing to use the same hydraulic systems for capturing and storing water. This is why during flash floods, impressive masses of water flow into the sea and into nature. On the other hand, a quantity of water loaded with fine particles is stored in dams. A small quantity of water infiltrates into the ground, while the largest mass of water returns to where it came from (the water evaporates). In this case, we are talking about the quantity of evaporated water that returns to the sky in the form of gas. During periods of drought, a season lasts 5 to 6 months (from June to October); this is the evaporation season par excellence. The waters of natural lakes, chotts, and dams rise into the atmosphere in the form of water vapor due to high temperatures. In addition to the high demand for drinking water for the population and the irrigation of agricultural land, the dam is currently unable to meet these water demands. This is a delicate situation that the dam is currently experiencing. For example, the image of a dam without water has become commonplace, even though a dam is supposed to store rainwater.

Another example: today's dam is equipped with a floating pumping station to exploit its "dead" volume. Even though the dam, with its appreciable capacity, resists evaporation, its storage capacity is reduced by the rise of silt deposits drained by flash floods during the short periods of the wet season. This is the image of a hydraulic system that has proven itself over the years, but today it is unable to fulfill its mission, which was to store surface water during the winter for reuse during the summer period. Dams of average capacity have dried up, such as those of Bakhadda, Mefrouch, Foum El Gherza, Boukourdane, Keddara. The evaporation rate records values of 2 m/year to 3 m/year (Remini, 2005b). This critical situation has pushed the population to opt for groundwater. The accelerated exploitation of underground reservoirs through the multiplication of drilling has caused the drawdown of the water table and we have even come close to depletion of the water tables in certain regions. Thus, neither surface water nor groundwater has been able to fully satisfy the growing demands for drinking water and irrigation water. Conventional water quantities are considered insufficient, which has pushed hydraulic services to opt for unconventional waters and more specifically the waters of the Mediterranean Sea. Obviously, it is necessary to get rid of the brine to obtain fresh water. This step of passing from seawater to fresh water requires desalination processes such as reverse osmosis, the most widely used process on the planet. Algeria, after more than 20 years since the long drought of the 2000s, has become a world pioneer in seawater desalination since it has acquired an infrastructure of 18 desalination plants with a desalination capacity of 3.7 million m^3/d. If today, we can say that the situation of the availability of water reserves has improved, it remains insufficient to meet the demand for water for all socioeconomic sectors (domestic, industry, mining and irrigation) which are constantly evolving. This is why the search for other water resources has become a priority for the Algerian government. These water resources are found in the water cycle; a quantity of water is lost in nature and in the sea. Another much larger mass of water evaporates into the atmosphere. This article proposes a series of hydraulic water capture systems that adapt to climate change.

ALGERIA, LAND OF WATER

With an area of 2.382 million km^2 and a perimeter of 5 km shared between seven countries and the Mediterranean Sea, Algeria shares land borders with Tunisia to the northeast, Libya to the east, Niger and Mali to the south, Mauritania and Western Sahara to the southwest, and Morocco to the west. It is also bordered by the Mediterranean Sea to the north (Fig. 1).

Two parts of the Algerian territory are distinguished; the north and the south of Algeria. The north of Algeria which includes the coastal basin (1.2%), the Tell basin (3.3%) and the high plateaus (9%). The south of Algeria which represents the Algerian Sahara with an area equal to 86.5% of the total area (Fig. 2).

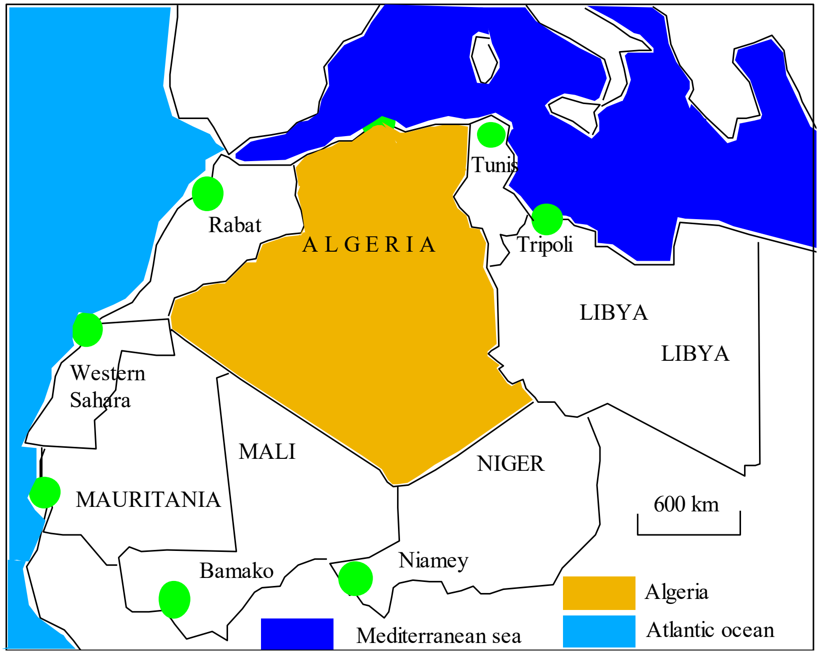


Figure 1: Geographic location of Algeria (Remini, 2025)

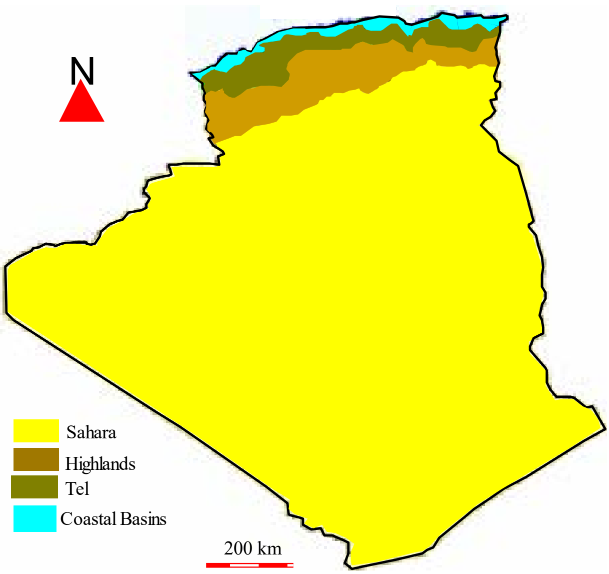
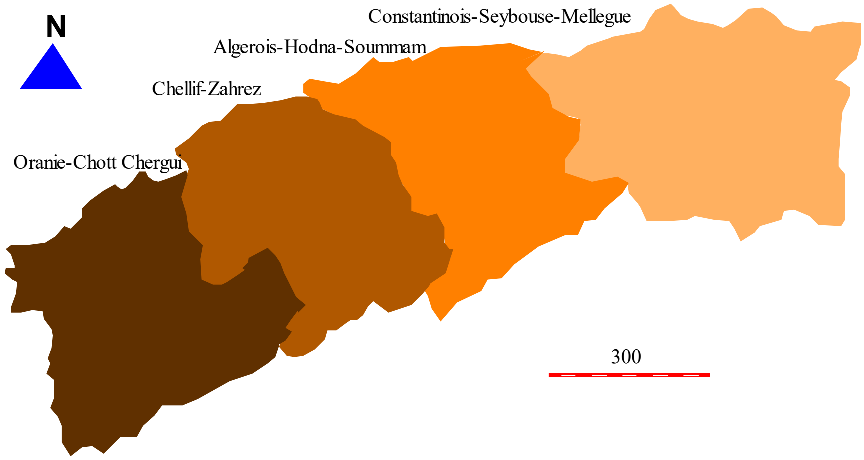


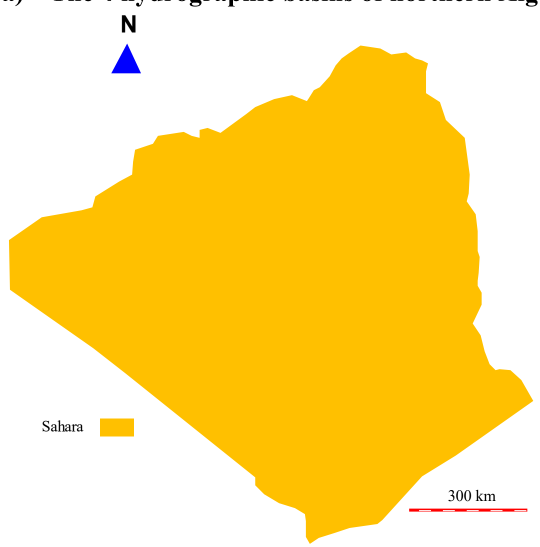
Figure 2: The 4 major areas of the Algerian territory (Source: Basins Agency; Remini Diagram, 2025)

The Algerian territory, covering an area of 2.382 million km², is subdivided into five hydrographic basins. This hydrographic organization was established by Executive Decree No. 96-100 of March 6, 1996, establishing the hydrographic basin and establishing the standard status of public management institutions. It defined the hydrographic basin as the topographic area drained by wadis and their tributaries, such that any flow originating within this area follows its route to the outlet. In 1996, the territory of Algeria was divided into five hydrographic basins (Figs. 3a and 3b):

- Oranie - Chott - Chergui
- Constantinois - Seybouse-Mellègue
- Algiers - Hodna - Soumam
- Cheliff - Zahrez
- Sahara



a) The 4 hydrographic basins of northern Algeria



b) Sahara River Basin

Figure 3: Algeria's five river basins (Source: Basins Agency; Remini Diagram, 2025)

Each of these two parts has enormous deposits of water resources. Coincidentally, whether for the north or the south of Algeria, the sky is kind since 100 billion m^3 is the average volume of water falling annually from the sky in each part of the Algerian territory. However, the subsoil of the southern part is much richer than that of the north, since it contains large reservoirs in the depths occupying an area exceeding 50% of the surface area of the Algerian Sahara. In addition to the Northern Sahara Aquifer System (NSAS), Algeria has 5 other transboundary aquifer systems. These are natural reservoirs hidden in the subsoil such as the Northern Sahara Aquifer system, the Mourzouk basin, the Iulleden-Tanezrouft-Taoudeni aquifer system, the Er-Rachidia-Bechar basin, the Tindouf aquifer system and the Meghnia aquifer (Remini, 2021; 2025) (Fig. 4).

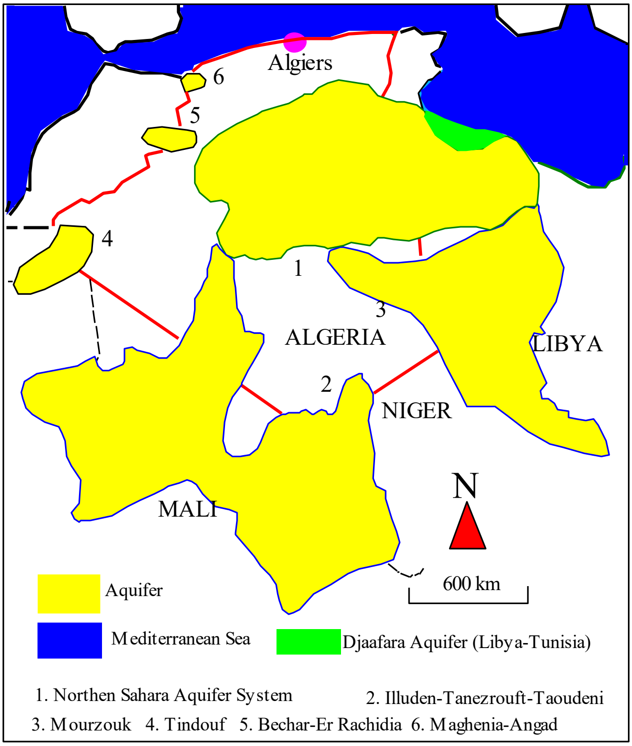


Figure 4: The main aquifers of the Sahara (Source: Sahara and Sahel Observatory; Remini Diagram, 2025)

No article has been written and no information has been provided on these 6 aquifers apart from that of the Northern Sahara Aquifer System (NSAS). The first article on all of these aquifer systems (6 in number) was published by myself in issue 47 of Larhyss Journal of the year 2021 (Remini, 2021). With an area of 54% of the total area of Algeria, which demonstrates the size of this water deposit hidden in the depths of the Algerian subsoil for several centuries. Unfortunately, no serious study has been carried out by the relevant services on this underground sea.

Table 1 summarizes the main characteristics of these large aquifers, which form an underground freshwater sea with a volume of over 75,000 billion m³, occupying a water surface area of approximately 1,285,000 km², representing 54% of Algeria's territory.

Table 1: Characteristics of Algeria's large aquifers (Remini, 2025). Sources: French Scientific Committee on Desertification (CSFD), 2020; Seguin and Gutirrez, 2017; SSO, 2020.

N°	Aquifer system	Volume km^3	Area 10^3 km^2	Annual extraction ($km^{3/}year$)	Shared countries
1	Northern Sahara	60.000	1.000	2.75	Algeria, Tunisia, Libya
2	Taoudéni/Tanezrouft/ Iulleden	15.000	2.500	0.34	Algeria, Nigeria, Niger, Burkina Faso, Benin, Mali, Mauritania
5	Mourzouk	4.800	450	1.7	Algeria, Libya, Niger, Chad
4	Tindouf	800	221	-	Algeria, Western Sahara
5	Er Rachidia – Béchar	0.320	70	-	Algeria, Morocco
6	Meghnia	0.085	30	-	Algeria, Morocco

It should also not be forgotten that in the Sahara several renewable upper aquifers have never been inventoried. In order to add a few billion m^3 of water to our freshwater stock, a colossal amount of work must be done to locate and determine the contours as well as the volumes of these new aquifers. In northern Algeria, the problem is completely different from that of the southern part, Algeria has 50 upper aquifers (water tables) with a total capacity of 2 billion m^3 (Remini, 2025; Remini. 2005a). The hydrographic network of northern Algeria has more than 50 large wadis that can drain 12.5 billion m^3 (Remini, and Amitouche, 2023). 83 large dams in operation have been built on this network to store approximately 8.5 billion m^3. Three large dams are in operation with a capacity exceeding 2 billion m^3. These are the Beni Haroun dams (capacity 960 million m^3), Koudiet Acerdoune Dam (640 million m^3), Gargar Dam (450 million m^3). A crucial problem affects the Algerian hydrotechnical infrastructure, it is the phenomenon of siltation which reduces the capacity of the dam lake and even blocks the drainage openings. Each year, our dams record an annual siltation equal to 65 million m^3/year (Remini, 2017). With climate change, this siltation rate will increase in the coming years, due to soil erosion and the undermining of wadi banks has increased in recent years following flash floods that cause sudden runoff. Algeria has a coastline of more than 1.600 km in length in contact with the Mediterranean Sea. This opening with a sea is a gift from Good; an inexhaustible source of water, but it is salt water. However, to exploit this mass of water, the salt must be removed. To this end, Algeria has built 18 desalination plants along the coast to produce 3.7 million m^3 of water/day. As for the Algerian Sahara, with an arid climate, has a particular and original hydrographic network which is made up of more than 70 large wadis. Unlike the wadi of northern Algeria, that of the Sahara is different, because it is characterized by very wide sections exceeding in some places 1 km and a length that can exceed 200 km and draining flash floods that can reach a flow rate of

1.500 m^3/s. However, given the desert climate that reigns on this arid expanse thus favoring the phenomenon of evaporation, only 3 dams have been built on this desert. These are the dams of Foum El Gherza, Djorf Torba, Brezina and Foum El Gueiss.

WORKING METHODOLOGY

For over 30 years, we have traveled throughout the Algerian Sahara, visiting all the major wadis of the Algerian Sahara, such as Mzab, Labiod, Metlili, Mzi, El Hay, Abdi, Djedi Biskra, El Hay, Abdi, Djedi, Ntissa, Tamanrasset, and others. All the oases of the Algerian Sahara have been visited multiple times. These are the oases of Mzab, the oases of Ziban, the oases of Souf, the oases of Touat, the oases of Gourara, the oases of Tidikelt, the oases of the Righ Valley, the oases of Ouargla, the oases of Bou Saâda, the oases of Soura, the oases of Metlili, the oases of El Guerrara, the oases of Berriane, the oases of Tiout, the oases of Boussemghoun, the oases of El Bayadh and the oases of Laghouat. We witnessed several times by chance particular events such as the arrival of flash floods, sandstorms and floods. Surveys were conducted among the ksouriens on the subject of water in the oases. We visited several times different ancestral hydraulic works. We were dazzled by the systems of the foggaras. Unique in the world, the Algerian foggara remains a sustainable hydraulic system that adapts to hyper-arid climates and even to a climate hostile to life. For more than thirty centuries, the foggara has ensured water security and consequently it has ensured the food security of the oasis. Foggaras have been adapted according to the hydrogeology of the environment and especially the nature of the water source. Before drilling the first deep borehole in the early 1940s to exploit the Albian aquifer, the Ksourians had been exploiting this Continental Intercalaire aquifer for more than 20 centuries. It was only in the early 1940s that some countries around the world exploited the alluvial aquifer by building underground dams. However, it turns out that this type of alluvial aquifer has been exploited for centuries through the use of foggaras. It is at the level of the Ahaggar oases that farmers dug around a hundred foggaras in the wadis of the Hoggar region. A foggara in the Tindouf oases exploited the alluvial aquifer of the Tindouf River for several centuries. In the early 1950s, the foggara was abandoned. It was in the early 1990s, during a study on spring dams that we encountered sand dams on the Labiod and Abdi wadis between Biskra and Batna. For us, this was a discovery, since no information indicates that Algeria had this type of dam, namely sand dams. During the 2000s, in the Mzab Valley, we encountered recharge dams for the first time. A discovery for us, since no study had been done on this type of dam. It is thanks to all this knowledge acquired on the diversity of hydraulic structures that we prepared this study entitled "Water capture techniques adapted to climate change."

RESULTS

Effect of climate change on conventional waters

Climate change has existed for centuries, but it is a slow phenomenon, such that adaptation occurs slowly without us realizing it. What worries scientists today is the acceleration of this climate change, which does not allow enough time for adaptation. Today, everyone is aware of and feeling this climate variation. It is the effect of humans that has caused this situation and produced a new, disrupted climate based on extremes. We are witnessing a climate revolt following human provocation. This new climate is characterized by two distinct seasons: a long dry period followed by a short-wet period. These dry periods last 5 to 6 months, with temperatures reaching 45°C during the months of July or August. This accelerates the evaporation of surface water and consequently dams will be the hydraulic structures most affected by this new climate.

Indeed, in recent years, the lakes of about ten dams have been completely depleted due to evaporation. We can cite a few dams that have seen their water capacity dried up in recent years. These are the Benkhedda, Mefrouch, Keddara, Boukourdane, and Foum El Gherza dams. The water level in several dams has reached the "dead" volume and consequently these dams have become unable to meet the excessive demand for drinking and irrigation water. The dam no longer plays its role of storing and distributing water. Indirectly, water withdrawals from underground reservoirs have increased, which has led to a decrease in the underground reservoir (water table). Cases of water table drawdown have been recorded in several places and we have even come close to drying up some water tables such as that of the Mitidja. Cases of road subsidence have been observed in the Mitidja region over the past twenty years. The increase in drilling along the Algerian coast has led to a significant drawdown of the water table, which has led to marine intrusion into the coastal aquifer. The change in direction and the reversal of the flow of salt water towards fresh water from the water table. The salt wedge flows from north to south, the water in the water table becomes increasingly salty and over time, the soil becomes salinized. Regarding the short winter season, it is characterized by the sudden drop in a significant amount of rainfall in a very short period. This causes the appearance of flash floods, which are simply Saharan floods that have moved from the Sahara to the countries of North Africa and the countries of the Mediterranean basin. In addition to the volumes of water drained by these floods, tons of mud are carried by these rivers. These floods are characterized by the rapid rise of wadis in record time. These floods are devastating and can cause material and human damage. Once again, it is always the dams that are the victims of this new climate during the wet season. Indeed, the torrential rains that fall on the watersheds, the aggressive runoff causes significant soil erosion. A massive departure of fine particles towards the sea, part of the sediments of which are trapped in the dam reservoirs. The difference in density of the two liquids causes the formation of density currents that propagate on the bottom of the dams to reach the outlets. When the bottom gates close, the density currents release these sediments to the bottom of the reservoir (Remini, 2017). Therefore, with each flash flood, thousands of tons of silt are brought back to the dam reservoirs and consequently the capacity of the dam decreases over time under the effect of successive sediment deposits. Finally, the dam's capacity is threatened by a double reduction due to the phenomenon of evaporation during drought and the phenomenon of siltation during wet periods. Unlike surface water storage reservoirs (dams) which empty, groundwater reservoirs fill during wet periods by the natural replenishment of the water tables.

Problem statement and proposed solution

As mentioned previously, it was only after all conventional water capture and storage methods had been exhausted that Algeria opted for unconventional water to meet its drinking and irrigation demands. Algeria relied on two types of unconventional water: water from the Mediterranean Sea and wastewater from treatment plants. To obtain good-quality freshwater, this water must undergo a highly complex treatment process. Thus, 18 desalination plants were built along the 1,600 km-long coastlines to demineralize this salt water and make it potable. As for wastewater, more than 210 treatment plants have been built throughout Algeria, producing a volume of purified water equal to 900,000 m^3. Algeria today has 46 million inhabitants, several thousand hectares of agriculture, several mining deposits, green hydrogen production, shale gas production, not to mention Algerian industry (all sectors included) which has seen remarkable growth in recent years. Algeria today needs more than 20 billion m^3/year to meet its annual water demand.

With an annual regulation flow estimated at 5 billion m^3/year from more than 80 dams in operation, 2 billion m^3 from groundwater in northern Algeria and 5 billion m^3 from the Northern Sahara Aquifer System, Algeria has a freshwater stock estimated at 12 billion m^3, representing an annual water deficit estimated at 8 billion m^3/year. Today, with climate change, dams no longer play their role and therefore can no longer supply the 5 billion m^3 of water per year. Siltation and evaporation are occurring in force; siltation occurs during the flood season and evaporation occurs during the drought season. A double reduction affects Algerian dams, more than 2 billion m^3 of silt are currently deposited at the bottom of the 83 dams (Remini, 2017). Evaporation occurs during periods of long droughts, which causes a loss of water that returns to the sky in the form of gas. Evaporation from dam lakes in Algeria reaches 3 m per year (Remini, 2005b). Therefore, it is this evaporation phenomenon that directly affects the useful volume and consequently, it is the regulated volume of water that will be infected by evaporation. This has caused the drying up of several dams such as Bakhadda, Foum El Gherza, Mefrouch. Other dams operate with their "dead" volume with the use of a small floating pumping station to exploit the waters of the dead volume. Since the dam is not playing its role, since the demand for water is not satisfied. This has caused an overexploitation of groundwater. Moreover, the capacity of the groundwater in northern Algeria is 2 billion m^3 and the total withdrawal is 1.9 billion m^3/year. This demonstrates the high degree of water withdrawal and the risk of depletion of the aquifers. Today, with this unregulated climate, the water deficit greatly exceeds 8 billion m^3/year. So, the question we must ask: How should we fill the deficit of 8 billion m^3? Before answering this question, it is interesting to know that the Algerian sky is very mild, since each year, 200 billion m^3 falls on the Algerian territory, 100 billion m^3 falls in the northern part and 100 billion m^3 in the Algerian Sahara. If we take the north of Algeria, we record 12.5 billion m^3 as flow in the hydrographic network. A quantity of 2 billion m^3 infiltrates into the subsoil of northern Algeria. So more than 85.5% of water that northern Algeria receives from the sky returns from where it came, that is to say more than 85.5 billion m^3 evaporates into the atmosphere (Fig. 5).

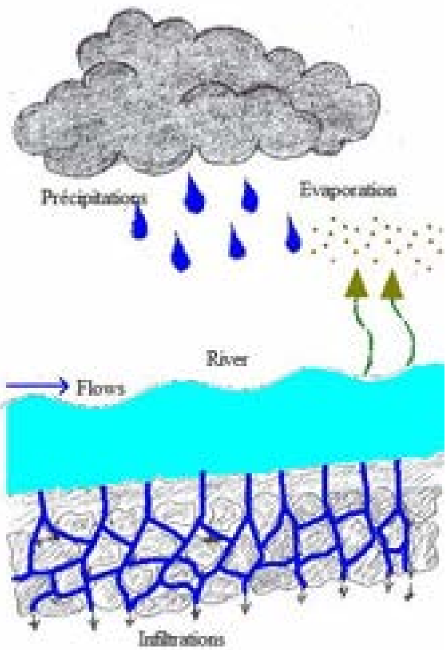


Figure 5: Water balance (Remini Diagram, 2025)

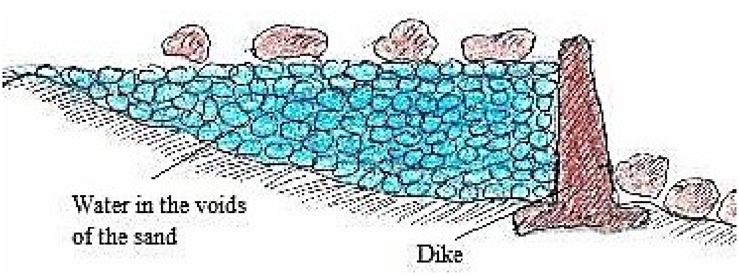
The solution to Algeria's water problem lies in history

To solve the thorny water problem facing Algeria and several other countries around the world due to climate change, a historical study is essential on water resources and the ancestral hydraulic developments carried out over the centuries in several regions of Algeria. The oasis remains a good example to follow in inventing hydraulic systems for capturing and storing water adapted to the current climate. It is interesting to remember that the oasis is the first region on Earth to ensure its water security in an arid climate hostile to life. The particularity of the Algerian oasis lies in the diversity of hydraulic developments adopted according to the hydrogeology and hydrology of each region. The oases of Touat, Gourara, and Tidikelt have invented an ingenious hydraulic system based on a slightly inclined underground drain to capture and transport groundwater to the ground surface. For more than 20 centuries, the Touat and Gourara oases have ensured the water security of the oases thanks to the foggara. Neither depletion nor drawdown of the water table has been recorded during the history of the foggara, despite a continuous and uninterrupted flow for more than 20 centuries. This demonstrates that the recharge of the water table is equal to the water abstraction from the water table by the foggara. On the other side, in the Mzab Valley, a rocky region with an arid climate records very low rainfall, however the flash floods that occur in the wadis of Mzab, Ntissa, Metlili carry impressive quantities of water in a very short period. For example, the flash flood of 2008 caused a flow of 1,200 m^3/s.

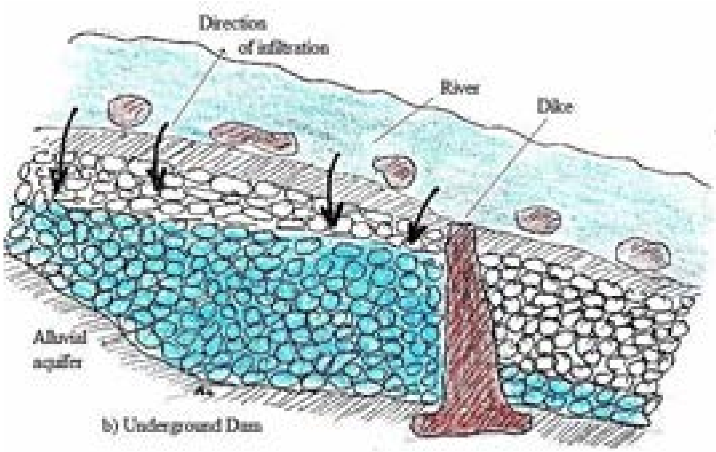
The farmers of Mzab know the value of water, since until today and for more than 7 centuries, the oasis dwellers celebrated the arrival of floods in the oases. One flood per year is sufficient to meet the demand for irrigation water and drinking water supply of the ksar provided that it takes maximum advantage of the flood water. To this end, an ingenious system of replenishing the alluvial aquifer was created. It is a hydraulic development based on threshold dams installed along the Mzab wadi as well as recharge reservoirs such as the Ahbas Bouchen and Touzouz as well as the large ancestral Beni Isguen dam. These hydraulic systems are responsible for accelerating the replenishment of the infero-flux aquifers to the detriment of evaporation from the lakes. Then the water stored in the subsoil is drawn from animal-drawn wells. They even installed traditional wells along the wadis, the role of which is not to capture groundwater, but to recharge the water table. In the oases of Sfissifa, Tindouf and Tamanrasset, farmers have been exploiting the infero-flux aquifers for more than 7 centuries through the foggaras system. With these examples, we can draw conclusions about the hydraulic systems that must be implemented today to make the most of floodwaters. Through these examples, farmers have understood that floodwaters must be protected from evaporation. Only storing surface water in natural reservoirs hidden in the subsoil is the only solution in an arid climate.

The solution for the new climate: hiding rainwater underground to quench thirst

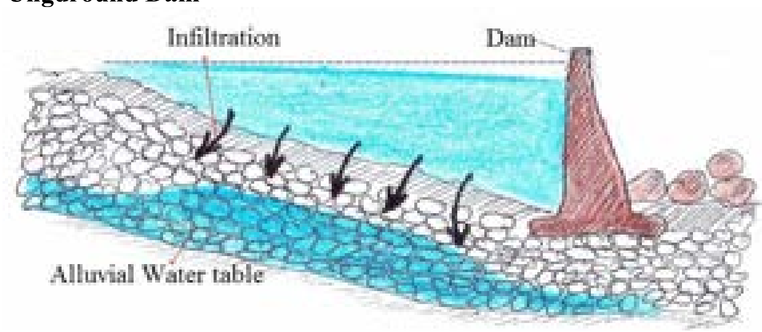
So, how can we make the most of rainwater once it reaches the ground in a debilitated climate based solely on extremes? Take full advantage of floodwaters before they reach the sea or are lost in nature. It is during the short flood period that hydraulic engineering must be implemented to capture and store a large volume of flash flood water to meet the high-water demand during long periods of drought. To protect floodwater from evaporation, hydraulic engineering must be adapted to this disrupted climate [Figs. 6(a), 6(b), 6(c), and 6(d)].



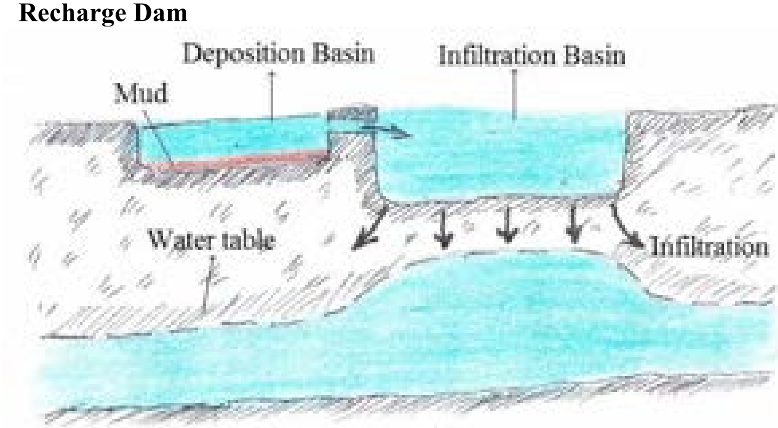
a) Sand Dam



b) Ungdround Dam



c) Recharge Dam



d) Infiltration Basin

Figure 6: Groundwater recharge techniques that should be implemented in arid countries (Remini Diagram, 2025)

Building more subsurface dams in river systems

No hydraulic structure can compete with a reservoir dam in terms of storing a significant quantity of surface water. However, with these climate changes, subsurface dams are becoming a priority over surface dams. Thanks to their low cost, simple construction, and hygienic water storage, subsurface dams can provide a simple and economical solution for optimal use of groundwater resources (Nohani and Mirazizi, 2025). The 1994 United Nations Convention to Combat Desertification suggested subsurface dams as a technology normally suited to economical water storage in arid and semi-arid regions (Apayden, 2009; Ahmed et al., 2016). Subsurface dams, or inferoflux dams, have now become essential for this new climate. The idea of capturing and exploiting the alluvial aquifer, or inferoflux, originated in the Algerian Sahara. What exactly is this Inferoflux aquifer? Quite simply, the water is found in the surface aquifer of the sandy bed of the Tamanrasset wadis, which are located at a depth varying from 0.5 m to approximately 4m (Gast, 1995). These are surface Inferoflux aquifers or alluvial aquifers that are replenished each year after the passage of floods and they flow under the river beds in the alluvium. They flow even if the wadis are dry on the surface (Remini and Achour, 2013). As we mentioned previously, it is in the oases of Tamanrasset, Sfissifa and Tindouf that the exploitation of the Inferoflux aquifer has been carried out for more than 7 centuries for the first time in the history of hydraulics (Remini and Abidi-Saad, 2019). At that time, farmers used the foggaras system to capture and transport water stored under the wadi bed to the gardens located below the water source. However, in the oases of Berriane, El Guerrara, Metlili and the oases of the Mzab Valley such as Ghardaïa, Beni Isguen, Mlika, Bounoura, and El Atteuf, the exploitation of the Inféroflux aquifer is carried out through traditional wells installed in the wadis. At the beginning of the 20th century, underground dams were put into operation in several countries around the world. In Japan, the first underground dam with a capacity of 20,000 m^3 was built in 1973. In 1981, the first two underground water dams were built in Ethiopia (Hanson and Nilsson, 1986). In Brazil, four underground dams were built in 1982 (Ishida et al., 2011). Algeria has about ten underground dams. We can cite the old Tadjmout dam located on the Mzi River in the wilaya of Laghouat. In this bed of the Mzi River, filled with sand, water flowed to a depth of about 5 meters and a width of 300 meters. The flow regulated by the Tadjmout dam varies from 400 to 800 l/s. It was in the early 1990s that the arid world discovered the performance and profitability of underground dams. Approximately 500 underground dams were built in Brazil to cope with droughts (Foster et al, 2002; Foster and Tuinhof, 2004). The underground dam cannot compete with the surface dam for quantitative reasons, but from a qualitative point of view the waters of the infero flux dam are much better than the waters stored in the surface dam. Infero flux dams are located in about 24 countries of the world (Fig.7).

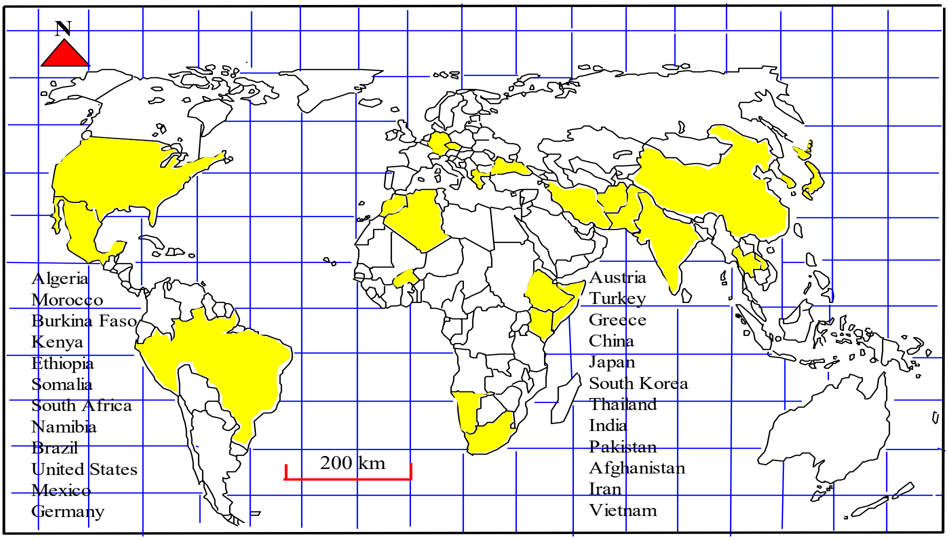


Figure 7: Location of underground dams in the world (Remini Diagram, 2025)

The existence of hydraulic dynamics in several wadis of the wilaya of Tamanrasset, since major flash floods occur every year, particularly during the June-September period. These flash floods feed the alluvial aquifers. For example, in the central Hoggar region, the amount of water in the alluvial aquifer is estimated at 5 million m^3 (Jacob and Alvera, 2011). In this region, underground dams supply the population with drinking water, but water demand remains insufficient. Other inferoflux dams must be built as soon as possible, since flash flood water evaporates naturally. Worldwide, recently commissioned underground dams have captured millions of m^3 of water. However, countries very rich in freshwater have built more than hundreds of underground dams, such as China and Japan; India, the United States, Kenya, South Africa, and Brazil. According to Kevin and Melvyn (2004), approximately 400 subsurface dams have been built in Brazil, the majority of which are in the state of Pernambuco. According to Ishada et al. (2011), 500 subsurface dams currently store water for livestock, irrigation, and domestic use. The typical height of these dams ranged from 1 to 4 meters above ground level. The effectiveness of a subsurface dam lies in its ability to store water in the ground. In Japan, the capacity of subsurface dam's ranges from 17,000 m^3 to 10 million m^3, and from 1.5 million m^3 to 4 million m^3 in South Korea (Nguyen, 2024). In Kenya, there are approximately 500 small and medium-capacity subsurface dams. When a flash flood occurs during the wet season, two parts of water are distinguished. One part of the water infiltrates the wadi bed between the particles and aggregates to reach the substratum. The water flows by gravity between the voids of solid particles, but the flow adopts a laminar regime. The second part of the water remains on the wadi bed and flows by gravity on the free surface and adopts a torrential regime. The water that flows on the wadi bed, a volume of which returns to the sky in the form of gas. In this case, the flow in the wadi is a temporary flow that occurs only during floods. However, the water that flows under the bed adopts a laminar flow but continues for a long period. Floods are needed to feed the flow under the wadi bed. Such a flow can take up to four years, depending on the evaporation rate. Just as we can build a dam on the ground to store floodwater flowing over the wadi bed, we can build a dam underground to store floodwater flowing under the wadi bed. A subsurface dam is a hydraulic structure that consists of retaining and storing groundwater by dikes during flood periods for reuse during drought periods. A subsurface dam is a medium-sized structure built across wadis whose beds are filled with aggregates. The dike can be made of masonry, concrete, clay, or impermeable material designed to reduce underground flow and promote groundwater recharge. The water retained by a subsurface dam is accumulated in geological formations. The water is stored in the pores or cracks of the rocks and the voids formed by the arrangement of aggregates (Fig.8).

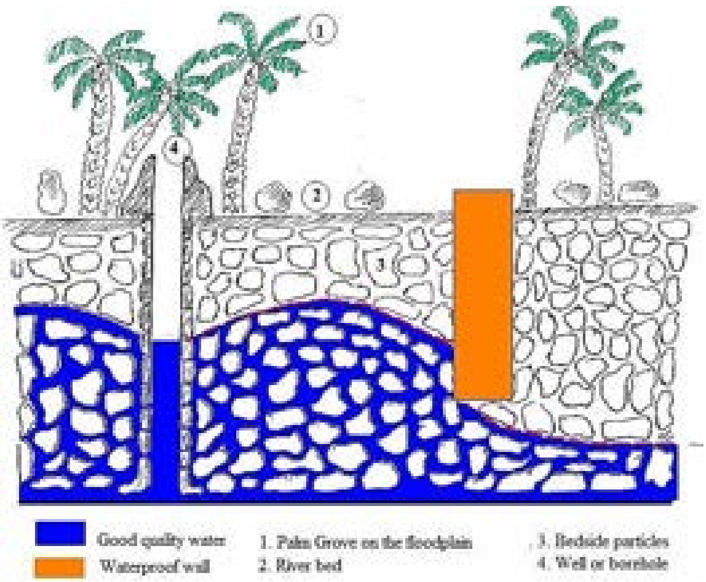


Figure 8: Approximate diagram of a subsurface dam (Remini Diagram 2025)

The voids contained in these soils, which determine the capacity of the subsurface dam, are estimated at 10 to 30% of the reservoir volume. To achieve a high-water volume, the reservoir must be closed at the bottom and laterally by low-permeability soils. The presence of an opening may hinder the filling of the subsurface dam reservoir. Finding a suitable site for a subsurface dam is much more complex than for a surface dam. The ideal location for a subsurface dam should be on wadi beds with a gradient coefficient ranging from 2 to 4% (MEFAD, 2022) and where the grain size of the sediments accumulated along the wadi and in the beds is that of sand. The construction of the Mefrouch dam on the wadi of the same name with a capacity of 13 million m^3. Mafrouch, a multi-arch inclined dam built of concrete, is intended to supply drinking water to the city of Tlemcen and part of the city of Oran as well as the irrigation of 4,500 hectares. Original, a unique dam which consists of capturing simultaneously groundwater and flood water. This is the Mefrouch dam put into operation in 1963 on the Algerian wadi with a capacity of 13 million of m^3, only this surface dam is seated on an invisible dam; a second dam but underground which captures the waters of the alluvial aquifer. So, the Mefrouch dam is original and it is the only one in the world. It is a mixed dam which includes a surface dam and an underground dam (Figs. 9 and 10).

Figure 9: A general view of the Mefrouch dam (Photo Remini, 2007)

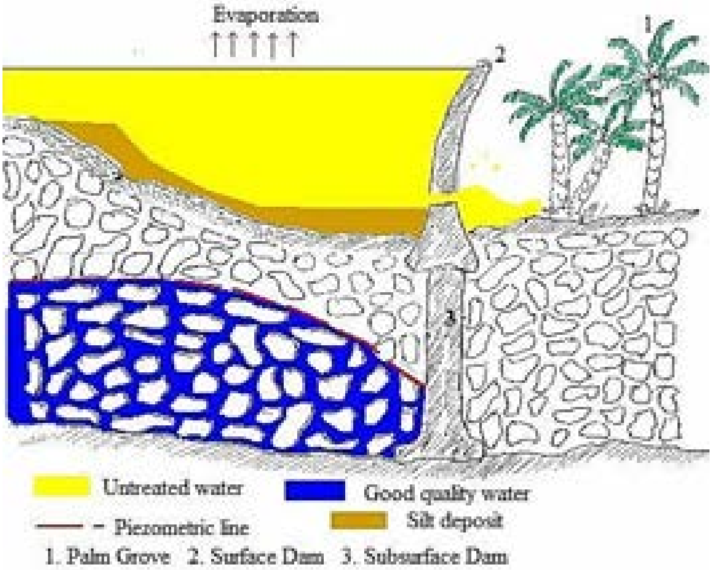


Figure 10: Diagram of a hydraulic system composed of a surface dam and a subsurface dam (Remini Diagram, 2025)

Estimating the capacity of a dam is not as simple as estimating the capacity of a surface dam due to the geological structures. The subsurface dam (obstacle) is built underground, generally in the alluvium of a river. Part of the dike is sometimes located above ground, with a Greager-type shape. The subsurface dam is more secure than the surface dam; it does not have a spillway. The subsurface dam's dike, anchored in the subsoil, offers good mechanical stability compared to the surface dam. Even if it is damaged by a flood, the damage is minimal and does not spread to areas downstream of the dam. The subsurface dam's reservoir is below ground level, so it requires pumping facilities to discharge water to the gardens located above the water table. However, we can use a slightly inclined horizontal pipe to obtain gravity. Therefore, the gardens located downstream of the dam can be irrigated by the gravity pipe (Fig.11).

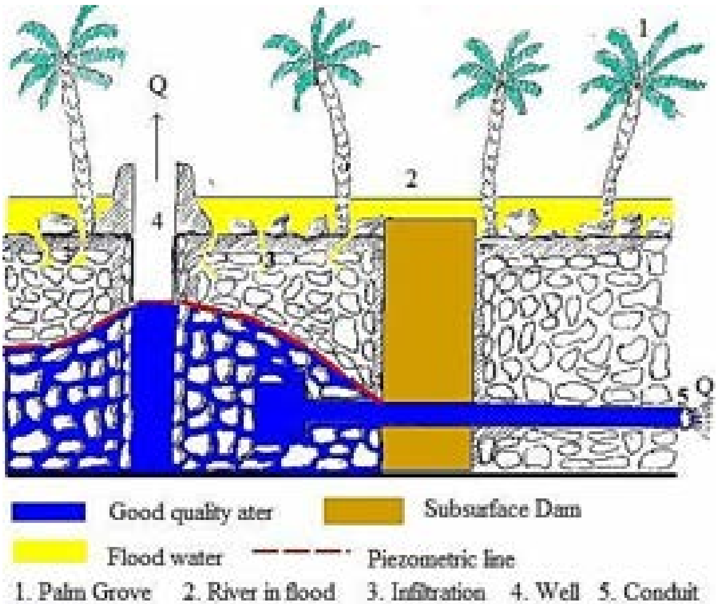


Figure 11: Approximate diagram of the water intake system of an underground dam (Remini Diagram, 2025)

With this new climate characterized by long periods of drought, evaporation is very active, which does not spare the waters of reservoirs. Thus, today, an average water height exceeding 2 meters in reservoirs evaporates and returns to the sky in the form of vapor. On the other hand, the water retained by underground dams, the water stored underground, is spared from the phenomenon of evaporation, since only a small amount of water evaporates into the atmosphere. The underground dam is a sustainable hydraulic system since it is designed to exploit the alluvial aquifer, which is replenished by sporadic floods. Therefore, the underground dam uses renewable water resources. If properly constructed, an underground dam has a lifespan of between 30 and 50 years (MEFAD, 2022).

Climate disruption can cause two irreversible hydraulic problems. These are the depletion of groundwater and the problem of marine intrusion into coastal aquifers. Regarding the first problem, intense evaporation from dammed lakes has caused a decline in the quantity of surface water. This new situation has pushed the population to exploit groundwater. However, in several regions, water withdrawals through boreholes and wells exceeded groundwater recharge. This is what happened during the drought that occurred in Algeria in the early 2000s. In parts of Mitidja, land subsidence was recorded following the drying up of the groundwater. The loss of water from pores and voids causes the soil layers to settle. This phenomenon is irreversible and therefore there is a risk of losing the aquifer (Fig. 12).

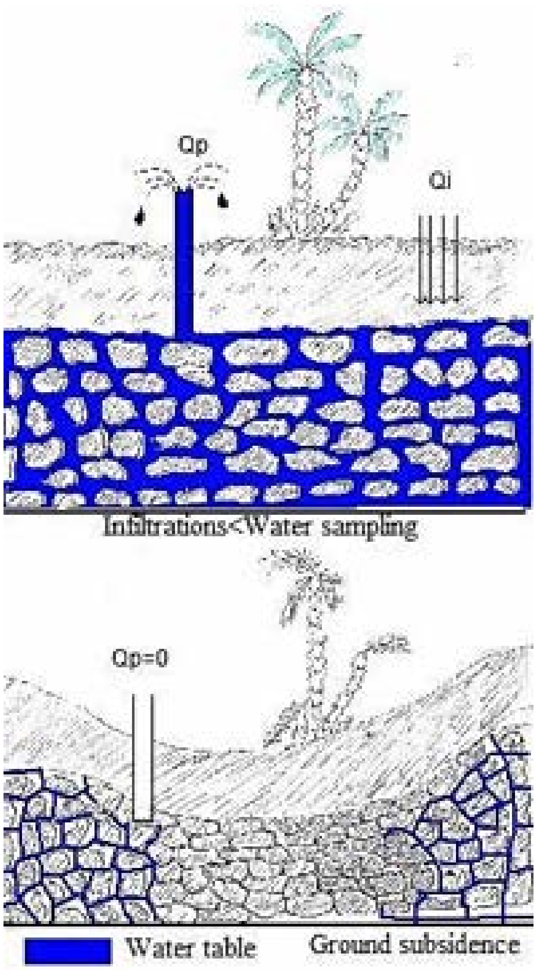


Figure 12: Approximate diagram of the groundwater dewatering process (Remini Diagram, 2025)

The second hydraulic problem concerns the phenomenon of marine intrusion into coastal aquifers. All coastal basins with a length of 1,600 km are threatened by this phenomenon. Indeed, these freshwater reservoirs are located at the border with the Mediterranean Sea. Initially, the water level of the groundwater (fresh water) is always higher than the seawater level (salt water), and fresh water flows into the sea (the hydrostatic force exerted by the groundwater is greater than the hydrostatic force exerted by the salt water). Since the hydrostatic force is a function of the water depth (h) and the density of the liquid (fresh water or salt water) (Remini, 2010), In its natural state, the hydrostatic force exerted by fresh water must always be greater than or equal to the hydrostatic force exerted by salt water ($Fn \geq Fs$) with Fn: force exerted by groundwater. Fs: hydrostatic force exerted by salt water from the Mediterranean Sea. The pressure exerted on groundwater by intense abstractions by multiplying drilling. This has caused a drawdown of the water table and consequently the hydrostatic force exerted by salt water becomes greater than the hydrostatic force of fresh water ($Fs \geq Fn$). In this case, the density current forms and propagates in the coastal aquifer. This density current is called a salt wedge by hydrogeologists. The propagation of the density current in the underground reservoir contaminates the water of the coastal aquifer and the salinity of the water spreads over the entire extent of the aquifer (Fig. 13).

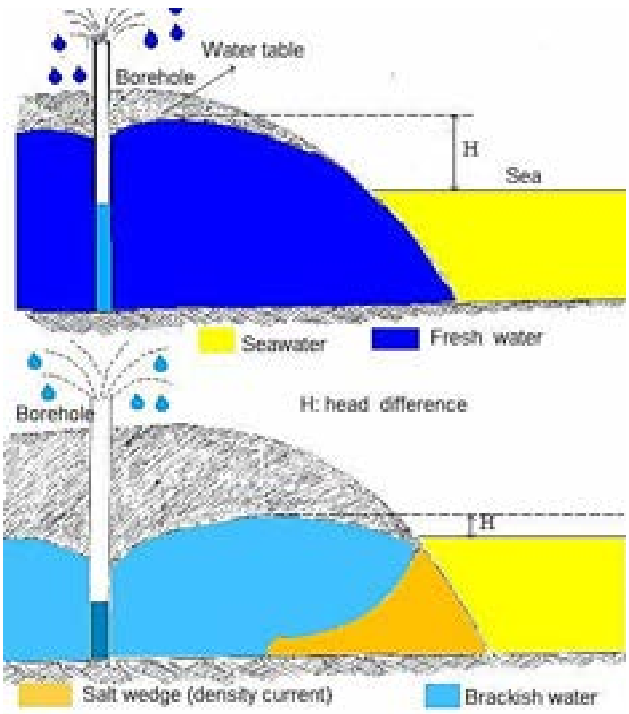


Figure 13: Diagram of intensive water withdrawal from the coastal aquifer, resulting in the appearance of a salt wedge that flows within the aquifer (Remini Diagram, 2025)

This phenomenon of marine intrusion into coastal aquifers has occurred in several locations along the Algerian coast. These include the regions of Tipaza (Bouderbala et al., 2016), Algiers, and Annaba. With climate change, this phenomenon will accelerate, and consequently, all coastal basins will be threatened by marine pollution. Density currents (salt wedges) will multiply, so what should be done in this case? Two solutions are available to answer this question: Artificially replenish the coastal aquifer using recharge basins to raise the water table's piezometric level. In this case, the hydrostatic force of the water table becomes greater than the hydrostatic force of the salt water (Fn ≥ Fs), the state of the water table returns to its initial position and the salt wedge disappears. As for the second solution, it is simply a matter of building an underground dam under the bed of the wadi before reaching the mouth. The dam dike will act as an impermeable wall that blocks the spread of the salt wedge and consequently pollution of the water table will be avoided (Fig. 14).

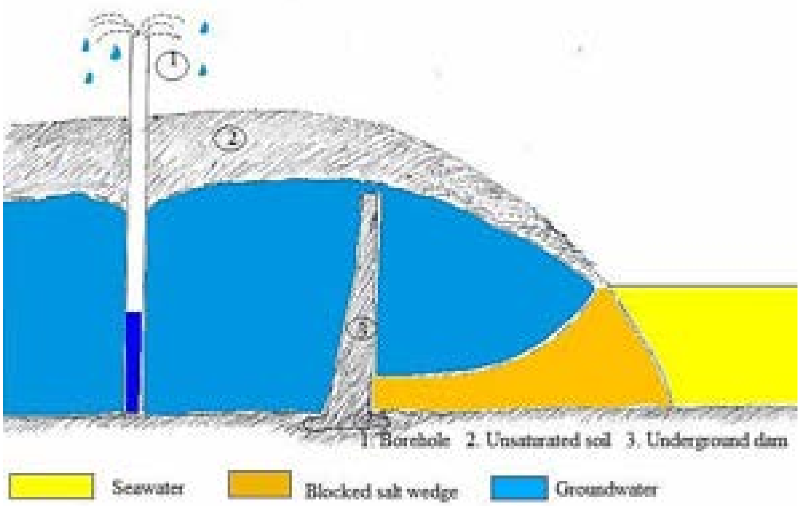


Figure 14: Diagram of a subsurface dam acting as an impermeable wall to prevent the advance of the salt wedge (Remini Diagram, 2025)

Sand dams: A forgotten structure

Subsurface dams and sand dams are two hydraulic systems designed to retain water during floods for reuse during droughts. However, the two dams differ in their construction and location. A subsurface dam is a structure designed underground. The dike is generally made of concrete or impermeable materials to block the flow of groundwater and raise the water table. Subsurface dams should be built during the dry season when groundwater flows are at their lowest. A sand dam can be defined as an open-air aquifer filled with sand to retain surface water in the voids formed by the arrangement of aggregates. The construction of a sand dam must be spread over several dry seasons. The dam is built at a height (h) above the wadi bed during the dry season.

During the winter season, floods carry a mass of material that is deposited following the dam wall. During the second dry season, the dam wall is raised to another height (h) and after the passage of one or more floods the sand is deposited again and so on until the project is completely completed. Filled with sand and gravel, the sand dam is finally in operation (Fig. 15). We can finally say that a sand dam is a surface aquifer.

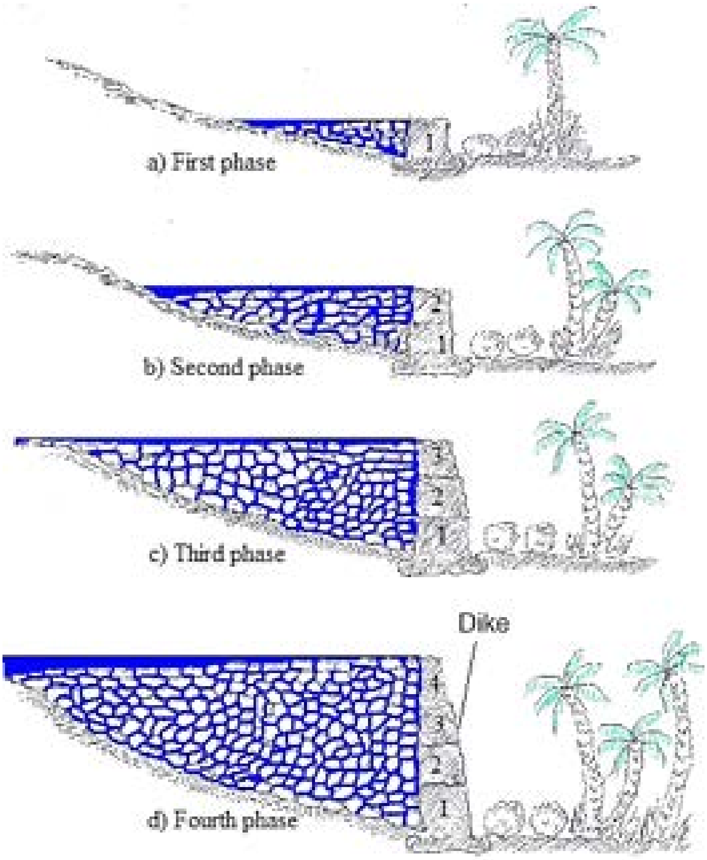


Figure 15: Stages of construction of a sand dam (Remini Diagram, 2025)

Suitable for an arid climate, the sand dam is a simple, inexpensive hydraulic system that requires little maintenance for water conservation. A sand dam can retain floodwater to recharge the water table. A sand dam is essentially a wall built in stages (each dry season) across and in the bed of a seasonal sandy wadi. It is most often made of reinforced concrete, masonry, or earth. Once the dike has reached its height, the flash flood carries sand, silt, and clay. Sand is deposited upstream of the dike, while fine particles such as silt and clay flow downstream over the obstacle. The dam rises, and at the same time, sand accumulates behind the dike. The total silting of the dam takes place on average in 4 flood seasons. The lifespan of a dam can be up to 50 years (Ruvival, 2021). The idea of building a sand dam is genius. Indeed, we consider this type of dam to be an open-air aquifer. In an arid region, it is forbidden to store water in contact with the air, the water risks evaporation. Hence the idea of protecting the water from evaporation. Building a dam and filling it naturally with sand to minimize the phenomenon of evaporation is a very good solution. The sand dam can be filled by the alluviation of the reservoir following erosion and solid transport which has become very widespread with climate change. During flood periods, tons of gravel and sand are drained into dams, which are built in layers of potential sand deposits, and finer materials are carried downstream (Sen, 2023). The most favorable sites for sand dam construction can be found between mountains and plains. The topographical slope of construction sites varies from 0.2% to 4%, but in extreme cases, it reaches 10 to 16% (Sen, 2023; Nilson, 1988). Sand dams do exist in Algeria; to date, we have identified about twenty dams, the majority of which are located in the Ziban and Aurès regions. Work is underway to inventory all sand dams in operation; such a study requires time and resources. After bibliographical research we were surprised to learn that these works are of worldwide reputation, since we have inventoried to date more than 26 countries which currently exploit this hydraulic system of surface water capture (Fig.16).

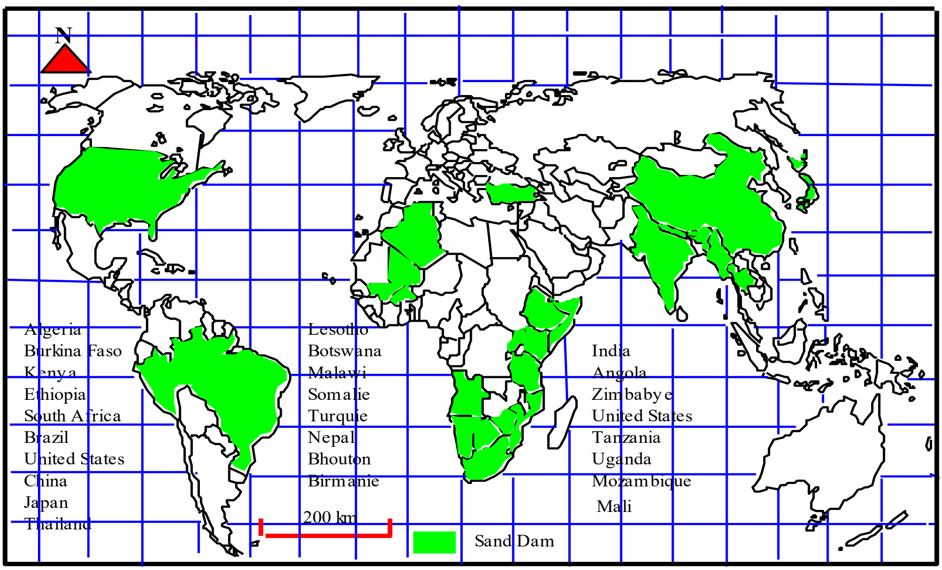


Figure 16: Location of sand dams worldwide (Remini Diagram, 2025)

We are pleased to learn that several African countries have been interested in sand dams since the 1960s. Kenya is the leading country on the African continent, having built more than 1,500 sand dams since 1960 (De Trincheria et al., 2015; Ayalew et al., 2021). The majority of these dams were built after 1990. Kenya is the leading country in the use of sand dams; more than 50% of the world's sand dams are located in Kenya (Ngugi, et al., 2020). It wasn't until 1973 that sand dams were used in the United States to develop water resources in arid regions (Sylvi et al., 2020). Several countries around the world have built sand dams, but unfortunately, we lack information and data-t-on this type of structure. Today, many countries intend to begin building sand dams. So, how come countries with very high-water resources have been building sand dams for more than half a century? These countries include China, Brazil, Japan, Turkey, and India, which proves the effectiveness of these inexpensive structures with very high-quality water catchments. At the same time, this type of structure is not known in Algeria, despite the fact that there are about twenty dams in operation. So, for us, Kenya remains an example of surface water management, as it has 1,500 sand dams in operation. As we mentioned earlier, a sand dam is a reinforced concrete wall built across a section of the river to capture groundwater trapped in the voids formed by the arrangement of sand particles (Fig. 17).

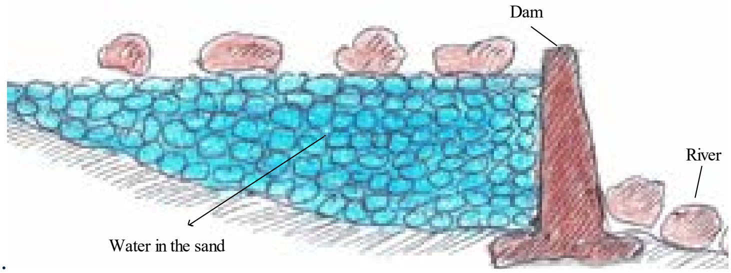


Figure 17: Diagram of a sand dam (Remini Diagram, 2025)

Flash floods bring water, sand, and clay particles. Once they reach the dam, the heavy particles are deposited in the reservoir formed by the concrete wall, while the fine particles continue on their way. Depending on the magnitude of the flood, it only takes one to three wet seasons to fill the dam with sand and gravel. The surface dam enters service after its reservoir is filled with water, so it can take one or more years to complete. The sand dam enters service after its reservoir is filled with aggregates in the first stage, followed by the water occupying the existing space between the particles in the second stage. In good quality sand, the volume of the sand dam is approximately 35% water (Beimers et al., 2001). Most of this water does not evaporate since it is protected by the sand. Evaporation decreases by 90% at 60 cm below the surface (Jacob and Alvera, 2011). The sand dam is built on a bedrock. For us, a sand dam is an artificial aquifer in the open air thanks to the wall built in a suitable location. Often, an aquifer is already present and the sand dam only increases its volume. Over time, the aquifer expands and the surrounding water table rises. Although the quantity of water captured by this type of dam is less than the surface dam, its water quality is much better than the surface dam. The exploitation of the water from the sand dam is carried out by wells or drilling upstream of the dam. Without power, water can be drawn downstream from the dam through a slightly inclined horizontal gallery; the flow is by gravity (Fig. 18).

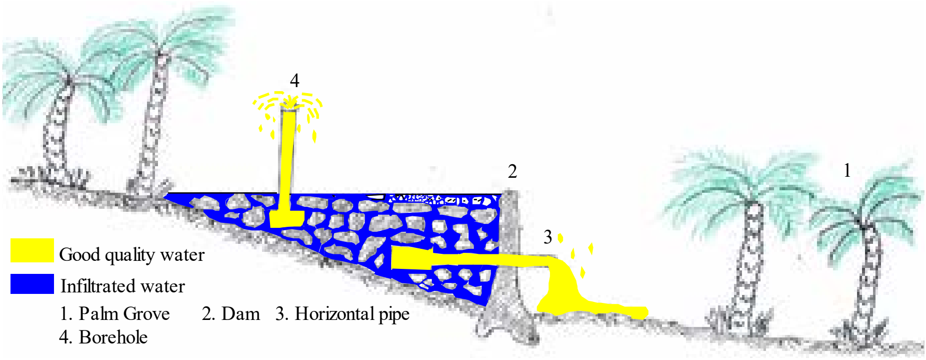


Figure 18: Approximate diagram of the sand dam (Remini Diagram, 2025)

For sand dams built in Algeria, each dam is equipped with two seguias made of cement or gypsum, or even carved into the rock. Rectangular in cross-section, the seguias carry high-quality water from the dam to irrigate the palm groves located in the floodplain downstream of the dam (Fig. 19).

Figure 19: A general view of the seguias emanating from the sand dam of the Mchounech oasis (Photo Remini, 2025)

It is only recently that we have discovered the existence of sand dams in Algeria. The uniqueness of these Algerian sand dams lies in the seguias that transport water from the dam to the gardens. About twenty sand dams have been identified in the Ziban and Aurès wadis (Figs. 20, 21, 22, 23, 24, and 25).

.

Figure 20: A general view of a sand dam on the Abid River (Photo Remini, 2025)

.

Figure 21: A general view of a sand dam on the Abid River (Photo Remini, 2025)

Figure 22: A general view of a sand dam on the Labiod Wadi (Photo Remini, 2025)

Figure 23: A general view of the sand dam after a flash flood (Photo Remini, 2025)

Figure 24: A general view of the sand dam on the Labiod River located in the Mchounech oasis (Photo Remini, 2025)

Figure 25: Une vue générale du barrage de sable situé sur l'oued El Hay (Photo. Remini, 2025)

Recharge dams

Unlike surface dams, which are built on low-permeability sites, recharge dams are built on permeable sites to promote and accelerate water infiltration into the subsoil and replenish the alluvial aquifer (Fig. 26).

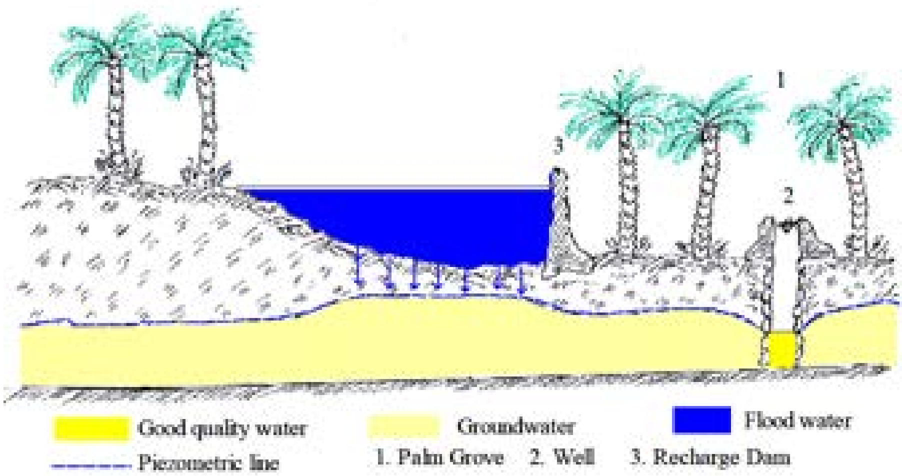


Figure 26: Simplified diagram of a recharge dam (Remini Diagram, 2025)

Consisting of an impermeable dike made of concrete, masonry, or gypsum, the recharge dam is built on a wadi. This type of dam originated in the Mzab Valley. Farmers invented these hydraulic structures to ensure water security in the era of climate change in the oases of Bounoura, Mlika, Atteuf, Ghardaïa, Beni Isguen, Berriane, El Guerrara, and Mettlili. Despite a rocky area and a lack of rainfall, apart from a few flash floods that occur in the Mzab Valley's hydrographic networks, thanks to these locally invented structures, farmers have managed to limit surface water evaporation and save millions of cubic meters per year. More than 50 recharge dams have been built in the region to replenish the aquifers and prevent the loss of several million cubic meters of water (figs. 27 and 28). Despite the lack of material resources, farmers have been able to build dams in suitable sites that meet all the topographic, hydrological, and hydrogeological criteria, such as soil permeability, to accelerate the recharge of alluvial aquifers.

Figure 27: The large recharge dam of the Beni Isguen oasis in the Mzab Valley (Photo Remini, 2010)

Figure 28: The large recharge dam of the El Atteuf oasis in the Mzab Valley (Photo Remini, 2010)

Relaunch and expand the construction of recharge dams throughout Algeria. These inexpensive hydraulic structures can help increase freshwater reserves. Recharge aquifers solely with flash flood waters. In a first phase, Algeria could begin the construction of around 100 recharge dams.

Recharge aquifers using infiltration basins

Infiltration basins are an artificial groundwater recharge technique. This hydraulic system generally consists of more than two basins located near wadis. When there are no suitable sites for the construction of a recharge dam, an underground dam, or even a recharge dam, the construction of infiltration basins becomes an essential option. Finding a suitable site around a wadi is the first step before beginning basin excavation. Soil permeability is an essential parameter for this type of hydraulic system. Once this hydrogeological parameter is met, the project begins directly. Then, all that's left is to divert the water from the nearest River. Through a manual opening, the water flows into the seguia directly from the wadi to the recharge station. The water passes into the first settling basin to allow the raw water to remove fine particles. This water passes into the infiltration basin to allow the water to quickly infiltrate into the subsoil to minimize evaporation of surface water (Fig. 29).

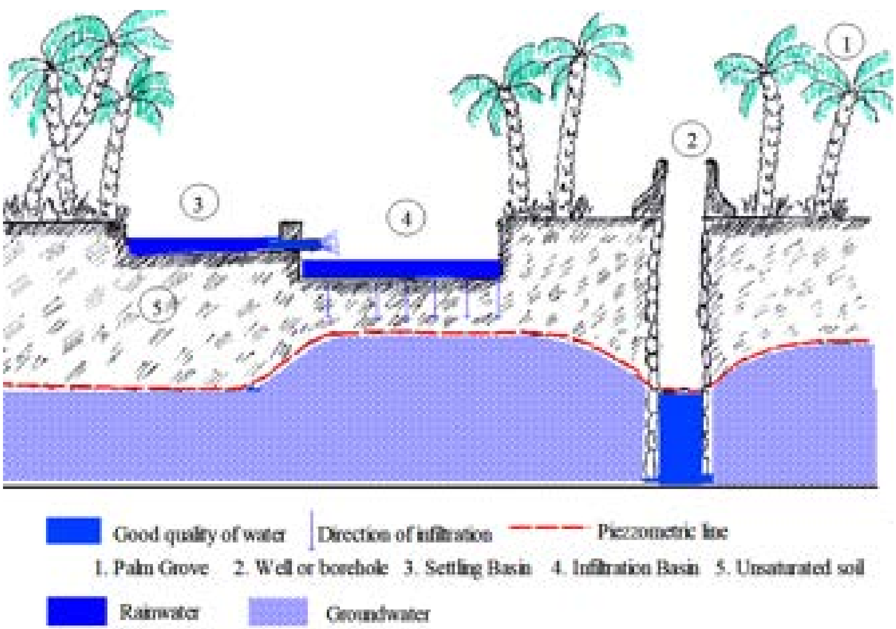


Figure 29: Simplified diagram of a groundwater recharge station (Remini Diagram, 2025)

Infiltration basins are simple and inexpensive installations, but require special attention to the quality of the surface water likely to be infiltrated. Otherwise, the project is based on digging two or three basins. Unfortunately, Algeria has not adopted this technique for a long time, except for an experiment conducted in the early 1990s by building four recharge basins in the wilaya of Blida, particularly in the commune of Bouinan. However, this project fell through. Unfortunately, there are currently no recharge stations in operation across the country. How can a country as large as Algeria lack a single groundwater recharge station using rainwater? It is time for water utilities to take this problem seriously, and yet the only refill station that existed near the El Harrach River in the commune of Bouinan during the 1990s produced very good results, since the water level rose in all the wells within a 20 km radius (Figs. 30 and 31) (Remini, 2008; Remini, 2010).

Figure 30: First infiltration basin of the Mitidja aquifer recharge station in Bouinan, Blida province (Photo Remini, 2024)

.

Figure 31: Second infiltration basin of the Mitidja aquifer recharge station in Bouinan, Blida province (Photo Remini, 2024)

Algeria has fallen far behind in this area of groundwater recharge. It should not be forgotten that the oases of the Mzab Valley were the cradle of groundwater recharge. Algeria must focus on groundwater recharge using rainwater. Building numerous infiltration basins should be a priority for the water supply services. In a first phase, approximately one hundred groundwater recharge basins will be built across the country.

Other groundwater recharge techniques

In addition to the four existing hydraulic systems, such as sand dams, subsurface dams, recharge dams, and infiltration basins, there are other water capture and storage techniques, which are generally traditional.

River bank filtration

Wadi bank filtration is a water abstraction technique in which water is pumped from the ground via the banks of a wadi. The captured water is therefore floodwater, reservoir water, or water released through dam gates, which has undergone pretreatment by passing through a short path through various types of sediment and soil to reach its catchment area. With a very slow flow, the water has plenty of time to absorb salts and eliminate dissolved and suspended pollutants and pathogens. Riverbank filtration is a simplified and highly effective technique for obtaining high-quality water; unfortunately, this technique has not been widely adopted across the country (Fig. 32).

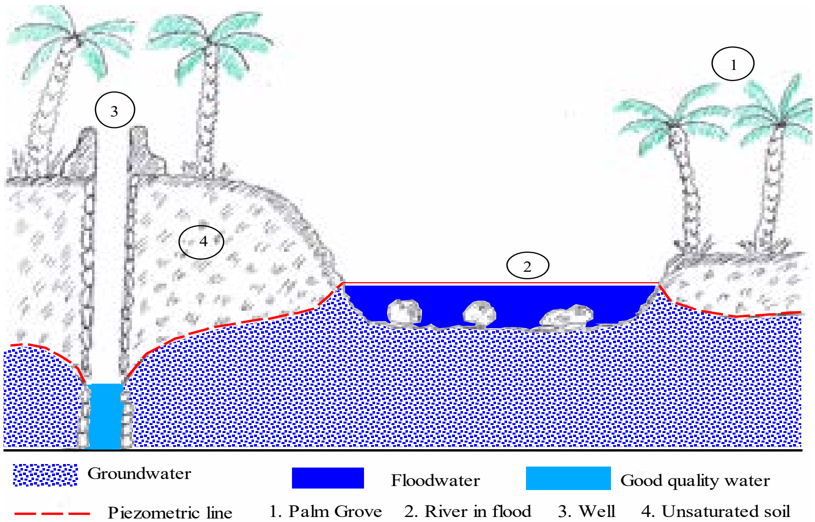


Figure 32: Simplified diagram of bank filtration (Remini Diagram, 2025)

It should be noted that there are three cases in Algeria where farmers use this filtration method to irrigate their gardens. Water releases from the Kef Eddir dam cause flows into the Damous wadi, recharging the alluvial aquifer, and at the same time, bank filtration is activated. A multitude of motor-driven pump wells have been installed along both banks, extending from the dam to the sea, over a distance of 8 km (Fig. 33).

Figure 33: Damous River: Periodic releases from the Kef Eddir dam cause the banks to filter down to reach nearby wells (Photo Remini, 2022)

Over a 12 km stretch of the El Hachem Wadi, water releases are carried out through the bottom gate of the Boukourdane Dam to replenish the alluvial aquifer and also to recharge the water level of farmers' wells. This bank filtration method has been applied in the Chéliff Wadi downstream of the Ghrib Dam. The dam's bottom gates trigger flows that recharge the alluvial aquifer of the Chellif Wadi and, at the same time, replenish the wells located on the banks of the Chéliff River.

Replenishment of the alluvial aquifer by dam releases

Despite the arid climate currently prevailing throughout Algeria, surface dams must continue to play their role. It should be noted that in recent years, several dams in northern Algeria have dried up due to evaporation. Carry out release operations through the dam's bottom gate to recharge the alluvial water table. Such operations can increase the efficiency of surface dams. However, the installation of baffle-shaped obstacles downstream of the dam significantly improves the efficiency of recharging the alluvial water table (Figs. 34, 35, and 36). It should be noted that these operations are currently being carried out in the Damous and El Hachem wadis. These improvements must be implemented for all surface dams currently in operation.

Figure 34: Damous River: Releases from the Kef Edditr dam to feed the alluvial water table (Photo Remini, 2023)

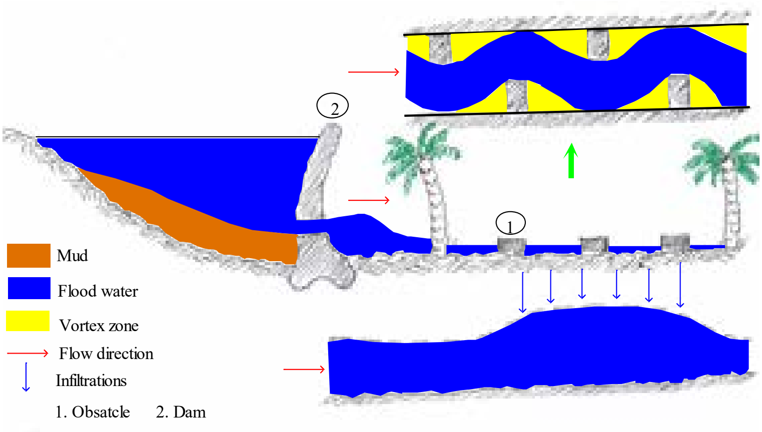


Figure 35: Obstacle technique (baffle shape) to accelerate the replenishment of the water table (Remini Diagram, 2025)

Figure 36: The chicane shape of the obstacles in a wadi is the best arrangement to accelerate the recharge of the alluvial aquifer (Photo Remini, 2004)

Garden flood irrigation

This operation consists of flooding the garden with large quantities of water from flash floods. They use raw water, i.e., floodwater loaded with fine particles. This water, very rich in nutrients, is released directly into the gardens to allow the soil to renew itself with each irrigation operation. Indirectly, these quantities of water remove fine particles from the soil, and the liquid infiltrates to recharge the water table (Figs. 37 and 38). These garden flooding operations have been carried out for seven centuries in the oasis gardens of the Mzab Valley. It should not be forgotten that the irrigation of gardens is carried out when floods arrive in the oases of Batna and Biskra.

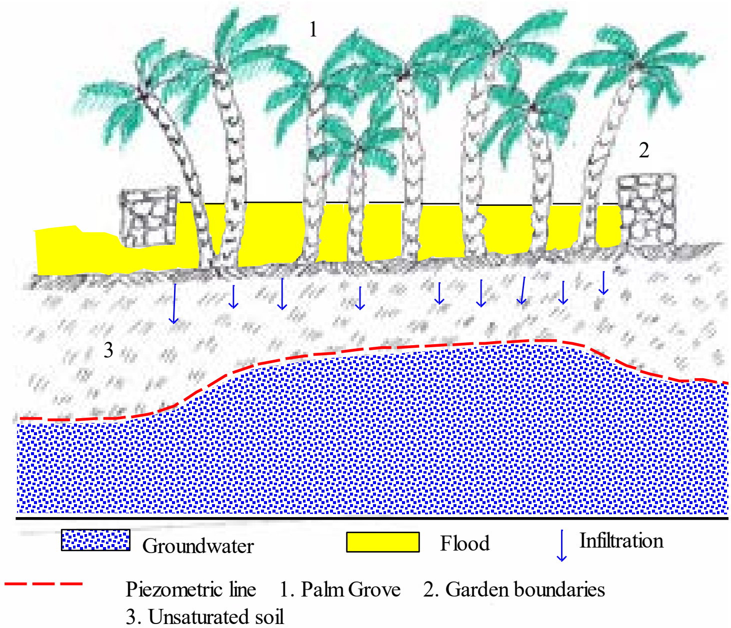


Figure 37: Simplified diagram of flood irrigation (Remini Diagram, 2025)

Figure 38: Overflow from a garden in the Berriane oasis flooded by a 2008 flood (Photo Remini, 2008)

Recharge through wells and boreholes

Recharging groundwater aquifers is an ancient technique practiced in the oases of Ghardaia, Beni Izguen, Bounoura, Melika, El Atteuf, Metlili, Beriane, and El Guerara for over seven centuries. This direct method is used when indirect techniques such as infiltration basins, garden flooding, and recharge dams cannot be applied due to the low permeability of the surface layers. Water injected into the structure will slowly recharge the aquifer. This is a cost-effective method because recharge is governed solely by gravity flow. Recharge by well or by drilling, the well has an opening below the edge at the same ground level in the direction of flow (Figs. 39 and 40). It is a direct replenishment of the water tables which requires special attention to the raw water which infiltrates directly into the water table. Today, direct recharge by drilling to replenish the upper water tables has not been applied on Algerian territory. There is no experience in Algeria.

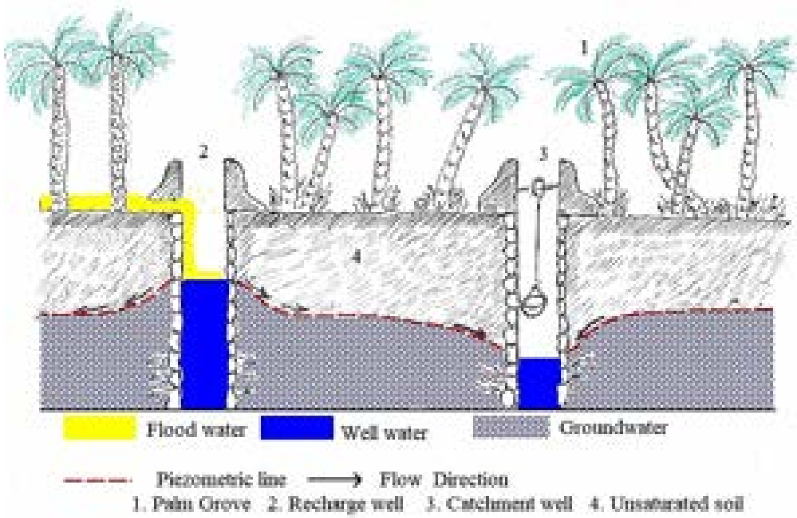


Figure 39: Simplified diagram of a direct replenishment operation by a recharge well (Diagram, Remini 2025)

Figure 40: Diagram of a traditional well designed to slowly recharge groundwater (Photo Remini, 2014)

DISCUSSION

This paper provides an answer to the question posed in the article published in Larhyss Journal, issue 41, 2019, entitled: "The climate is changing, water is becoming scarce, what can we do?" (Remini, 2019). Before answering this question, it is worth recalling that the hydrological year has been altered by climate change. A hydrological year has two seasons: a long dry period of more than six months characterized by high temperatures and consequently intensified evaporation. A short-wet period characterized by sudden precipitation that causes flash floods draining large quantities of water in a few hours (Remini, 2023). The new climate is based on two extreme parameters: floods and droughts. Reservoir dams are the hydraulic structures most affected by the effects of climate change. Indeed, dams are threatened by a double loss of capacity. During the winter, flash floods cause significant soil erosion, with a large amount of soil being deposited at the bottom of the dams. The rapid siltation of dams causes a rapid regression of dam reservoirs during the winter period. The quantities of water stored by dams during the winter will be lost in the form of vapor into the atmosphere due to evaporation. In recent years, some reservoir lakes have completely dried up, while other dams have operated solely with the dead volume using a floating pumping station. With this new climate, the surface dam has become incapable of fulfilling its role and, consequently, the dam is unable to meet the demands for irrigation and drinking water supply. This catastrophic situation has pushed hydraulic services and the population to turn to groundwater. This has put pressure on groundwater withdrawals, leading to a lowering of the water table, and in some areas of the Mitidja region, we have even recorded ground subsidence due to the drying up of aquifers. Why does climate change force us to review current hydraulic water capture and storage systems, such as surface dams, for example? As we demonstrated at the beginning of this discussion, dams are the first victims of climate change. During wet periods, which are characterized by flash floods draining large quantities of water and mud, all rainwater drainage systems and urban sewage systems, as well as dam spillways, are now undersized to cope with new flash floods. To protect these dams from the danger of flash floods, the spillways for the planned dams have been oversized and a second spillway has been built for the dams in operation. However, during periods of drought, dams naturally empty through evaporation from their lakes. Therefore, surface water is threatened by evaporation. It is worthwhile to give an idea of the significant quantities of evaporated surface water worldwide. To ensure Algeria's water security in the era of climate change, every drop of water must be recovered and stored. To this end, Algeria has four main water sources (Fig. 41).

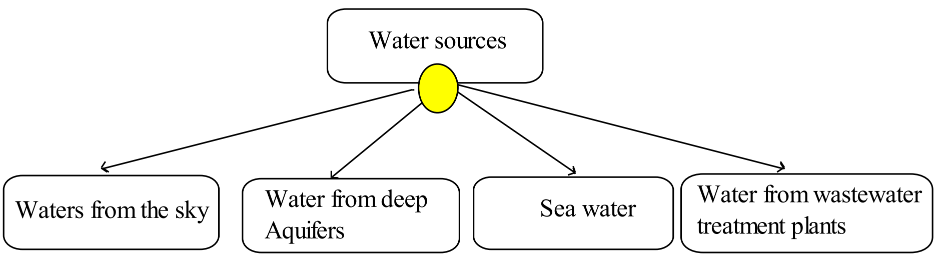


Figure 41: The four main sources of water (Remini, 2025)

Each country in the world receives its share of water from the sky, that is, a gift in the form of precipitation, the quantity of which depends primarily on the country's geographic location. However, once this amount of water reaches the ground, it can return to its source, meaning it evaporates into the atmosphere. This can be explained by the poor management of this gift from the sky. The amount of water collected and stored depends on material resources, hydrology, hydrogeology, and the proper management of this resource. The annual gift of water from the sky in the form of precipitation over land amounts to an average of 119 trillion m^3, of which 74 trillion m^3 evaporate into the atmosphere, representing more than 60% of total precipitation. The remaining 45,000 km^3 flow into lakes, reservoirs, and rivers, or infiltrate the ground and replenish groundwater. This provides an idea of evaporation from reservoir waters. In 2000, water losses through evaporation from dams and artificial reservoirs worldwide amounted to 210 billion m^3.

In Algeria, the skies are mild; annual precipitation averages 200 billion m^3, of which 100 billion m^3 falls in northern Algeria and 100 billion m^3 falls in the Algerian Sahara. In northern Algeria, of the 100 billion m^3 of precipitation, 85.5 billion m^3 returns to the sky (Remini, 2005b). To successfully recover and store a significant amount of water from the sky in the era of climate change, we suggest hydraulic structures that adapt to this new climate, which is based on two extremes: a significant amount of water drained by flash floods during the wet season. If this amount of water is not properly stored, it risks evaporating during drought. Therefore, any hydraulic development carried out today must take into account the evaporation parameter. In this case, hydraulic structures are needed that store rainwater in reservoirs protected from evaporation. Quite simply, precipitation water must be hidden underground. To this end, new hydraulic systems for capturing and storing water must be created. This is how we proposed hydraulic structures capable of storing rainwater underground. These are underground dams, sand dams, recharge dams, and infiltration basins. A sand dam is a reinforced concrete wall built across a River to retain groundwater in the sand. During heavy and irregular seasonal rainfall, water and silt flow over the dam, while the heavier sand settles to the bottom. After one to three rainy seasons, the dam fills with sand, which serves as a water storage reservoir. In good quality sand, the volume of the sand dam is approximately 35% water (Beimers et al., 2001). Most of this water does not evaporate because it is protected by the sand. Evaporation decreases by 90% 60 cm below the surface (Borst et al., 2006).

Sand dams, which we refer to as artificial unconfined aquifers, are found in more than 26 countries world wide. Kenya is the world leader with more than 1,500 sand dams. More than half of the total number of sand dams in the world are located in Kenya (Ngugi, et al., 2020). Of the twenty or so countries worldwide, that operate this type of dam, we estimate that around twenty are in operation. Brazil, China, and Japan are among the countries that have built these artificial aquifers. Only in Algeria have farmers made modifications to these sand dams and equipped them with seguias (open-surface canals). Built on both banks of the wadi, the two seguias transport water from the dam to gardens located on the wadi's floodplain (Fig. 42).

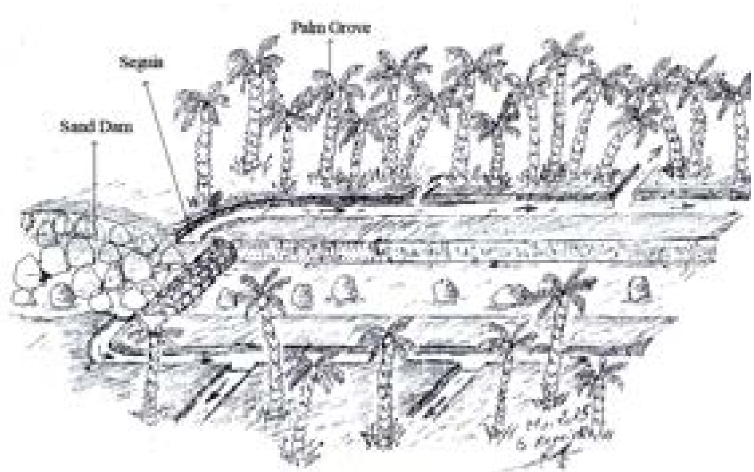


Figure 42: Diagram of a sand dam development and water transport sequences (Remini Diagram, 2025)

These small, inexpensive structures, requiring modest technology, can be widely deployed throughout Algeria. We suggest that the water authorities build more of this type of dam to store more water and reduce water loss through evaporation. Considering the water quality, we propose building dams in series and in cascade to prevent more water from flowing into nature and to avoid rising to the sky in the form of gas (Fig. 43).

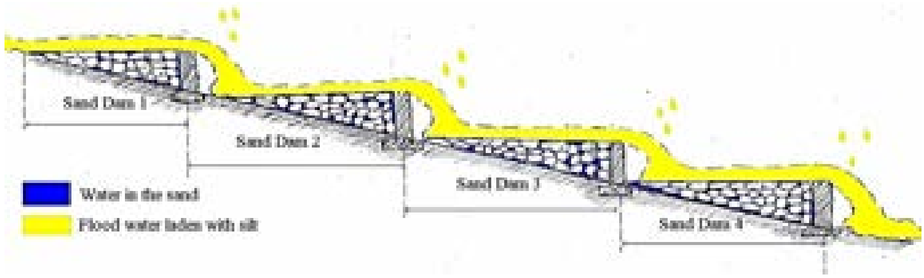


Figure 43: Cascading sand dams to better capture flash flood waters (Remini diagram, 2025)

The second type of dam, the inferoflux dam or subsurface dam is an effective solution for alleviating drought for people, animals, and even plants. We agree with the idea of building subsurface dams (Ishida et al., 2003; Borst and de Haas 2006; Hoogmoed 2007; Sen, 2023; Salahaldin, 2014). Unfortunately, the scientific literature on subsurface dams is insufficient. The construction of subsurface dams improves groundwater storage to capture groundwater flow and contributes to raising the water table, particularly in Quaternary alluvial layers (Raju et al., 2006). Today, these dams are preferred over surface dams due to their near-zero evaporation losses, superior efficiency and functionality, lower construction cost, less risk of pollution, and reduced land use even upstream. They are economical, efficient, and sustainable for local water supply management. In addition to groundwater resource management, appropriate sites and construction designs enable economical, efficient, and sustainable development. A geographic information system (GIS) has been proposed to identify suitable sites for the construction of these dams (Jamali et al., 2013; Dehghani Bidgoli and Koohbanani, 2021). Although there are different types of subsurface dams, many of them have not been as useful as expected due to lack of sufficient scientific and technological assessments. The choice of site could prove to be wise.

Algeria is among the first countries to adopt the subsurface dam; a dozen operating dams have been built in the wilayas of southern Algeria such as Tamanrasset, Adrar, Illizi and Laghouat. The Tadjmout subsurface dam is the oldest in Algeria since it was built on the Mzi River in the early fifties. It should not be forgotten that the population of Tamanrasset city drinks water from the subsurface dam. We have just discovered for the first time, the Mefrouch dam which is a mixed dam which is both a surface dam and an underground dam, that is to say, a dam which stores both the alluvial water table by infiltrations and the dam lake which is filled by the flash flood waters drained by the Mefrouch wadi. Original, the Mefrouch dam is the only dam in the world in view of the bibliography that we consulted. I suggest that this type of dam become widespread across the planet given its usefulness. This special dam is the hydraulic structure best suited to arid climates since it captures the maximum amount of water from a flash flood drained by the river. This includes both the water flowing over the wadi bed and the water flowing under the wadi bed. The third hydraulic structure concerns the recharge dam. This hydraulic structure is typically Algerian. Originally from the Mzab Valley, some forty recharge dams have been built along the hydrographic network of the watersheds of the Mzab River, the Ntissa River, the Metllili River, and the Berriane River. The role of these dams is to store flash flood waters during wet periods, not for reuse during droughts, but to replenish the aquifers. This recharge dam therefore acts as an intermediary between the wadi and the aquifer. Recharge dams must be built throughout Algeria. For the fourth hydraulic development, which concerns artificial groundwater recharge basins, the groundwater recharge station through the basin system consists of a seguia that acts as a diversion from the main wadi to the first basin, which serves to settle fine particles. The clear water flows to the second or third basin, which is intended for groundwater recharge. This is a development that does not require a large investment or cutting-edge technology. It is sufficient to conduct raw water analyses before reaching the basins. It is a shame that a country like Algeria does not even have a single groundwater recharge station. Hydraulic services must take things seriously to build a hundred infiltration basins across Algeria.

The four hydraulic structures we proposed were designed to store more rainwater and prevent further precipitation losses before it is lost in nature or rises to the sky through evaporation. These four hydraulic structures play the same role, which is simply replenishing the water table. However, each hydraulic structure has its own criteria for choosing the right site. Therefore, taking these criteria into account, we build the hydraulic system that meets these criteria. Therefore, for each wadi, we must build at least one hydraulic structure according to the site's characteristics, which must be adapted to each hydraulic structure.

There is also the typically Algerian covered dam called the Djoub, which is designed to store surface water. The water is protected from evaporation. Generally intended for watering livestock and camels, the covered dam is built in the middle of the wadi. Equipped with several openings located in the direction of flow to store flood waters in record time given the speed of flash floods. Our hope is to see this covered dam become widespread across Algeria's hydrographic networks (Figs. 44 and 45).

Figure 44: A general view of the Covered Dam in the Metlili region (Photo Remini, 2022)

Figure 45: A general view of the covered dam in the Metlili region (Photo Remini, 2009)

After the first source of water from the sky, we move on to the second source of water, which concerns water flowing in the direction of the Albian flow. Algeria has a water deposit hidden for several centuries deep in the Algerian subsoil. Algeria has six transboundary aquifer systems. These are natural reservoirs hidden in the subsoil, such as the Northern Sahara Aquifer System, the Mourzouk Basin, the Iulleden-Tanezrouft-Taoudeni Aquifer System, the Er-Rachidia-Bechar Basin, the Tindouf Aquifer System, and the Meghnia Aquifer. For the third source of water, which concerns seawater, Algeria has a 1,600 km opening onto the Mediterranean Sea, an inexhaustible source of water, except that this water is salty. To make it drinkable, the salts must be removed. To this end, desalination plants must be built near the seabed. Today, Algeria has acquired invaluable expertise in desalination. In the early 2000s, and to cope with a long period of drought, Algeria accelerated the desalination of seawater. Today, Algeria has 18 large desalination plants producing 3.7 million m^3/day. This water is currently used for drinking water supply, but in a few years, with the construction of other desalination plants, Algeria will switch to irrigation using desalinated water. The fourth source of water concerns the water from the plants. Obviously, after purification, this purified water can be used for irrigation. Regarding the purification plants located in the Sahara, the purified water can be discharged into the chott and the sebkhas to boost biodiversity.

Algeria today needs 20 billion m^3/year to meet all its water demands, which are growing significantly. Whether in terms of agricultural area or quantity of agricultural products, the agricultural sector has evolved dramatically over the past 5 years. The mining sector is currently experiencing very active momentum with the opening of several deposits, particularly the Ghar Djebilet megaproject in the wilaya of Tindouf, which exploits one of the largest iron deposits. The energy sector is expanding, particularly with the exploitation of shale gas and green hydrogen. Not to mention industrial development with several openings of several companies, particularly in the automotive sector. All of this socioeconomic development in Algeria, as well as demographic change, requires an increase in the capacity of Algeria's freshwater reserves. Today the Algerian population exceeds 45 million inhabitants, but we estimate that the Algerian population will reach more than 80 million inhabitants in the year 2060. A population has almost doubled that of today and at the same time socioeconomic development requires a quantity of water exceeding three times more than today's quantity, i.e., more than 60 million m^3/year. The annual demand for water will exceed 80 million m^3 by 2060. Therefore, to avoid a water deficit and ensure Algeria's water security in the years to come, resorting only to desalination of seawater will not definitively resolve water security. Therefore, resorting to sky water becomes an essential operation. That is, the hydraulic structures we recommended above. Sand dams, underground dams, recharge dams, and infiltration basins are becoming a priority for hydraulic services. Catch up and launch several projects to be carried out in the short term to acquire know-how and technology. So, everything needs to be reviewed in the coming years in the fields of research and higher education. In the research field, there are very few studies on these structures adapted to climate change. As far as higher education is concerned, hydraulic programs must take into account all these hydraulic structures that adapt to climate change. Water resource management in the coming years will become more complex. A significant number of hydraulic structures of different types will be built on the national territory and more particularly in the Sahara. The significant number of desalination plants that will be built on the 1600 km coast. The significant number of kilometers of pipelines that will be built for the transfer of water from one region to another or from one dam to another dam. The large aquifer systems that are found in the Algerian subsoil occupy a total area of 1,285,000 km^2, or a total percentage of 54% of the Algerian territory. These are the Northern Sahara Aquifer system, the Taoudéni-Tanezrouft-Iulleden Aquifer system as well as the Mourzouk basin, the Tindouf aquifer, the Bechar-Er-Rachidia aquifer and the Meghnia aquifer. Regarding the renewable aquifers of northern Algeria, the number of groundwater exceeds 37 aquifers which contain 2 billion m^3 of water. In southern Algeria, apart from a few aquifers which are known as the aquifers of Ghardaïa, El Oued and Touggourt… Several aquifers have not yet been inventoried. Not to mention also the water networks of northern Algeria and the Algerian Sahara are very dense and contain more than 150 wadis, so billions of m^3 of water flow and evaporate. The number of activated sludge treatment plants and treatment plants by spreading evolves over time. The construction of mineralization plants for brackish water from deep aquifers increases from one year to the next. Not to mention the significant number of drillings and wells carried out on the national territory. Huge as a number of hydraulic structures, so in this case, how to manage all this number of hydraulic structures? How to manage transboundary aquifers? How to manage water flows in the hydrographic network? How to manage large dams and water transfers? How to manage desalination plants? So, in this case, very good management of water resources throughout the national territory and more particularly in the Sahara. Today, it is impossible for a single basin agency to continue to manage the water resources of the entire Algerian Sahara. In view of the major socio-economic projects that Algeria has started in the short and medium term which require impressive quantities of water, we suggest that the entire territory be divided into 8 hydrographic basins to better manage water resources (Remini, 2024):

1. Oranie - Chott - Chergui Hydrographic Basin. 2. Chelif Zahrez Watershed
3. Constantine - Seybouse - Mellègue Watershed
4. Algiers - Hodna - Soumam Watershed
5. Western Saharan Piedmont - La Saoura - Hamada Guir - Tindouf Watershed
6. Tassili N'Ajjer - Ahaggar - Tanezrouft Watershed
7. Touat - Gourara - Tidikelt Watershed
8. Mzab Chebka - Oued Righ - Souf - Ouargla Watershed

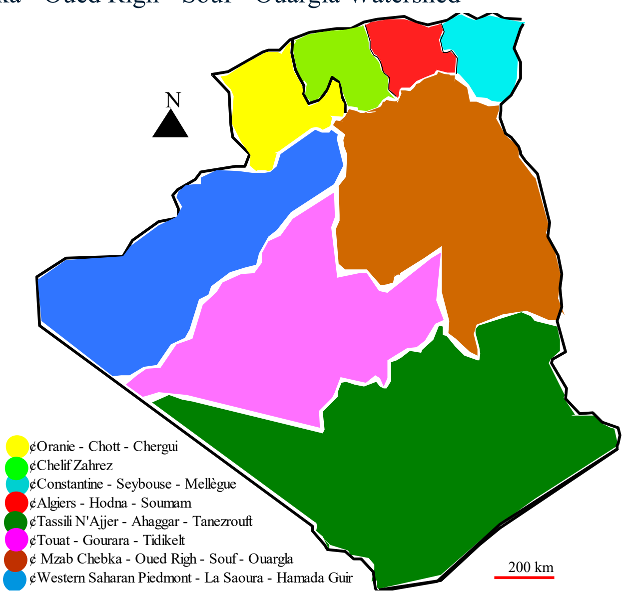


Figure 46: The boundaries of the four hydrographic basins of the Algerian Sahara (Remini diagram, 2025)

CONCLUSION

As we mentioned at the beginning of this paper, Algeria has four main water sources. These are groundwater, aquifer water, seawater, and wastewater treatment plant water. Algeria currently requires 20 billion m^3 of water. However, this annual water demand is changing over time and will reach 80 billion m^3 by 2060. However, climate change has significantly complicated the country's water situation. So, in this case, to meet all water demands, Algeria has four main water sources:

- 1st source: air water, water from aquifers that are not or only slightly rechargeable,
- 2nd source: water from aquifers that are not or only slightly rechargeable,
- 3rd source: sea water,
- 4th source: water from wastewater treatment plants.

Regarding the first source, Algeria's skies are mild, with an average of 100 billion m^3 of precipitation falling on northern Algeria alone. Approximately 85.5% of precipitation returns to the sky through evaporation. So, in this case, how can we capture at least 10% of the total precipitation that evaporates into the atmosphere? Build hydraulic structures that adapt well to climate change, i.e., hydraulic systems that reduce the evaporation rate. Based on research conducted over the past thirty years on water capture and irrigation techniques in the oases of the Algerian Sahara. Ancestral hydraulic structures adapted to the arid climate have been invented by farmers for centuries. The inferoflux aquifer has been exploited for more than 7 centuries in the oases of Tamanrasset, Sfisifa and Tindouf by the use of foggaras. In the early forties, the underground dam was invented to exploit the Inferoflux aquifer. The oases of Mzab are the first regions that invented artificial recharge of aquifers by the use of thresholds on watercourses. In this study, four hydraulic systems were highlighted to generalize them throughout the country. These are the underground dam, the sand dam, the recharge dam and the infiltration basins. These 4 hydraulic systems must be carried out according to the hydrogeological and hydrological criteria for each region. It is time to build these hydraulic systems throughout the country to acquire dam technology. These hydraulic structures must be included in university programs taught as part of undergraduate and master's programs.

Regarding the second source of water from non- or poorly rechargeable aquifers, Algeria has six transboundary aquifers. These are the Northern Sahara Aquifer system, the Taoudéni-Tanezrouft-Iulleden Aquifer system, as well as the Mourzouk Basin, the Tindouf Aquifer, the Bechar-Er-Rachidia Aquifer, and the Meghnia Aquifer. All these deep reservoirs occupy a total area of 1,285,000 km^2, representing a total of 54% of Algeria's territory. Today, Algeria exploits more than 5 million m^3 each year. For the third water source, Algeria has a 1,600 km long opening to the Mediterranean Sea. This eternal water source is impossible to quantify. However, this water is salty and therefore undrinkable. Therefore, drinking water production plants must be built along the coast. Today, Algeria has 18 desalination plants that produce more than 3.7 million m^3/day. The fourth water source concerns the water from wastewater treatment plants after decontamination. This water can be used for irrigating agricultural land. It is impossible to continue managing all four water sources on a territory covering 2.382 million km^2. To this end, we suggest dividing the Algerian territory into eight watersheds:

- Oranie - Chott - Chergui watershed.
- Chelif Zahrez Watershed
- Constantine - Seybouse - Mellègue Watershed
- Algiers - Hodna - Soumam Watershed
- Western Saharan Piedmont - La Saoura - Hamada Guir - Tindouf Watershed
- Tassili N'Ajjer - Ahaggar - Tanezrouft Watershed
- Touat - Gourara - Tidikelt Watershed
- Mzab Chebka - Oued Righ - Souf - Ouargla Watershed

Declaration of competing interest

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

Acknowledgments

Since the 1990s, I have traveled throughout the country, particularly the Sahara, in search of everything related to water. The oasis dwellers have taught me a great deal about their hydraulic expertise. I would like to sincerely thank all the people I met during my travels in the oases of the Algerian Sahara. Whether it was the National Water Resources Agency or the provincial hydraulic directorates, a huge thank you goes to everyone who provided me with the necessary data and information. Through this work, I discovered a magnificent people, a great country, a beautiful country: Algeria.

REFERENCES

APAYDEN A. (2009). Malibogazi groundwater dam: an alternative model for semi-arid régions of Turkey to store and save groundwater, Environmental Earth Sciences, Vol. 59, Issue 2, pp. 339- 345.

AHMED M.F, OMED Y., RAZA M.A., ISMAIL S. (2026). Groundwater dams, general characteristics and Historical development, Journal of Faculty of Engineering & Technology, Vol.23, No 1, pp. 121-128.

BORST L., HAAS S.A. (2006) Hydrology of Sand Storage Dams: A Case Study in the Kiindu Catchment, Kitui District, Kenya, Master Thesis of Hydrogeology, Vrije Universiteit (VU), Free University, Amsterdam, The Netherlands.

BOUDERBALA A., REMINI B., SAAD HAMOUDI A. (2016). Geoelectrical investigation of saline water intrusion into freshwater aquifers: A case study of Nador coastal aquifer, Tipaza, Algeria. Geofísica internacional, Vol. 55, N° 4, pp. 239-253.

BEIMERS P.B., VAN EIJK A.T., LAM K.S., ROOS, B. (2001). Improved Design Sand – Storage Dams, Project Report, Sahelian Solutions (SASOL) Foundation, Nairobi, Kenya.

CSFD (2020). (French Scientific Committee on Desertification). (2020). Deep water resources of the Sahara Desert and its arid and semi-arid borders, Thematic fact sheets, No 14, 3p.
www.csf-desertification.org

DEHGHANI BIDGOLI R., KOOHBANANI H. (2021). Site selection for underground dam construction by fuzzy algorithm in GIS platform, ECOPERSIA Journal, Vol. 9, No 3, pp. 159–168.

EYTAN GUR E., SPUHLER D. (2010). Sand Dams and Subsurface Dams, Sustainable Sanitation and Water Management (SSWM), Accssed March 2, 2025.

https://sswm.info/sswm-solutions-bop-markets/improving-water-and-sanitation; services-provided-public-institutions-0/sand-dams-and-subsurface-dams

FOSTER S., AZEVEDO G., BALTAR A. (2002). Subsurface dams to augment groundwater storage in Basement Terrain for Human Subsistence-Brazilian Experience, World bank, Groundwater Management Advisory Team (GWMATE) Case Profile Collection, 5.5.

FOSTER F., TUINHOF A. (2004). Brazil, Kenya: Subsurface dams to augment groundwater storage in basement terrain for human subsistence, World Bank Sustainable Groundwater Management Lessons from Practice, pp.1-8.

JACOB H., ALVERA S. (2011). Water Harvesting through Sand Dams, Echo Technical Note, No 70, 12 p.

HANSON G., NILSSON A. (1986) Ground-water dams for rural-water supplies in développent countries, Groundwater, Vol. 24, No 4, pp. 497–506.

HOOGMOED, M. (2007) Analyses of Impacts of a Sand Storage Dam on Groundwater Flow and Storage Groundwater Flow Modelling in Kitui District, Kenya. Master Thesis Hydrogeology, Vrije Universiteit (VU), Free University, Amsterdam, The Netherlands.

ISHIDA S., TSUCHIHARA T., OSHIMOTO S. (2011). MASAYUKI I. (2011). Sustainable Use of Groundwater with Underground Dams, Japan Agricultural Research Quarterly (JARQ), International Research Center for Agricultural Sciences (JIRCAS) Publishing, Vol. 45, No 1, pp.51 – 61.
http://www.jircas.affrc.go.jp.

ISHIDA, S., KOTOKU, M., ABE, E., FAZAL, M.A., TSUCHIHARA, T., IMAIZUMI, M. (2003). Construction of Subsurface Dam and Their Impact on the Environment, Rudarsko-Metalurški Zbornik (RMZ) -Materials and Geoenvironment, No 50, pp. 149-152.

GAST M. (1998). Foggara, Berber Encyclopedia, Vol. 19, pp. 2868–2880, Online Edition: Posted 1 June 2011 on OpenEdition Journals, document F34. http://encylopidiéberbere.revues.org

KEVIN T., MELVYN B. (2004). Underground dams: a practical solution for the water needs of small communities in semi-arid regions, Scientific communications, Terre et Eau, Vol. 1, No 1, pp. 63-65.

MEFAD (Algerian Ministry of the Environment and the Fight Against Desertification). (2022). Underground dam. Collection of technical data sheets.https://niger-gdte.net/books/4-techniques-de-mobilisation-des-eaux-et-infrastructures-rurales/page/47-barrage-souterrain-ou-de-sable

NILSSON A. (1988). Groundwater Dams for Small-Scale Water Supply, Book-length monograph, Intermediate Technology Publications Ltd, London, The United Kindom, UK, 69p.
ISBN 1-85339-050-X (978-1-85339-050-0)

NGUYEN MINH N. (2024). Solution of Subsurface dam for water supply, Proceeding of the International Conference on Green Energy: Intelligent Transport Systems – Clean Energy Transitions (GreenEnergy 2023), 22–24 November 2023, Kyiv, Ukraine, published in the E3S proceedings series by EDP Sciences, Vol. 508., Article Number 08012.
https://doi.org/10.1051/e3sconf/202450808012

NOHANI E., MIRAZIZI S. (2015). Importance and Role of Underground Dam Mirazizi, International Journal of Innovative Research in Engineering & Science, Vol. 5, No 4, pp. 36-40.

NGUGI K.N.K., GICHABA C.M.M., KATHUMO V.M.V., ERTSEN M.W.M. (2020). Back to the drawing board: Assessing siting guidelines for sand dams in Kenya, Sustainable Water Resources Management, Springer Nature, Vol. 6, No 58.
https://doi.org/10.1007/s40899-020-00417-4

OSS (Sahara and Sahel Observatory). (2020). Water in our regions, Institutional monograph (Book-length report), OSS Publishing, Tunis, Tunisia, 120p.

REMINI B., ACHOUR B. (2013). The foggaras of Ahaggar: disappearance of a hydraulic heritage, Larhyss Journal, No. 14, June, pp. 149-159

REMINI B. (2019). Algeria: the climate is changing, the water is becoming scarce, what to do? Larhyss Journal, No 41, pp. 181-221

REMINI B., ABIDI SAAD N. (2019). The foggara of Tindouf (Algeria): a declining hydraulic heritage, Larhyss Journal, No 39, pp. 215-228.

REMINI B., AMITOUCHE M. (2023). Desalination plants search good qualityraw water, Larhyss Journal, No 55, pp. 243-267

REMINI B. (2025). Algeria's groundwater an untapped strategic resource for water security. Larhyss Journal, No 61, pp. 401-431

REMINI B. (2010). The water problem in Algeria, Larhyss Journal, No 8, pp. 27-46

REMINI B. (2017). A new approach to managing dam siltation, Larhyss Journal, No 31, pp. 51-81

REMINI B. (2005a). The water problem in Algeria, Book, Algerian Office of University Publications (OPU), 162 p.

REMINI B. (2005b). Evaporation of reservoirs in arid and semi-arid regions: Algerian examples, Larhyss Journal, No 4, pp.81-89.

REMINI B. (2020). From the foggara to the underground dam, the alluvial tablecloth, a solution for arid regions, Larhyss Journal, No 41, pp. 297-308.

REMINI B. (2023). Flash floods in Alegria, Larhyss Journal, No 56, pp. 267-307

REMINI B. (2021). The Sahara: a wind dynamic on surfaceand water in depth, Larhyss Journal, No 47, pp. 189-207.

RUVIVAL (2021). Sand dams, RUVIVAL Toolbox, Hamburg University of Technology (HOOU/RUVIVAL), Germany, Retrieved September 20, 2025, from: https://www.ruvival.de/sand-dams/

SALAHALDIN S.A., FOAD A.A., SARKAWT G.S., NADHIR A.A., SVEN K. (2014). Evaluation of Selected Site Location for Subsurface Dam Construction within Isayi Watershed Using GIS and RS Garmiyan Area, Kurdistan Region, Journal of Water Resource and Protection, Vol. 6, No 11, pp. 972-987.

SEGUIN J.J., GUTIRREZ A. (2017). Water resources of the African continent: scarcity and abundance, Geosciences: The Bureau of Geological and Mining Research (BRGM) Journal for a Sustainable Earth, No 21, pp. 58–66.

SIVILS B.E., BROCK J.H. (1981). Sand dams as a feasible water development for arid regions, Journal of Range Management, Vol. 34, No 3, pp. 238-239.

ŞEN Z. (2008) Wadi Hydrology, Book-length monograph, Chemical Rubber Company (CRC) Press, Taylor & Francis Group, 368p.

ISBN: 978-1-4200-6154-3 / 1-4200-6154-2; eBook ISBN: 978-1-4200-6155-0

ŞEN Z. (2023). Longitudinally and laterally trench-supported subsurface dam innovative design procedures, Water Supply, Vol. 23 No 2, pp. 8-21.
DOI: 10.2166/ws.2023.023