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CLIMATE CHANGE
A THREAT TO ALGERIA'S WATER SECURITY

REMINI B.

Professor Emeritus, Department of Water Science and Environment, Faculty of Technology, Blida 1 University, Blida 9000, Algeria.

reminib@yahoo.fr

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ABSTRACT

From the dam to the desalination plant, the climate has shifted from freshwater to seawater. Exceeding 1,35 billion of m^3/y of drinking water produced by 18 desalination plants, Algeria has made significant progress in increasing its national freshwater reserves. However, the volume regulated by the 83 dams has decreased due to longer summers and flash floods that carry tons of silt to the dams. Siltation and evaporation, two characteristics of today's climate, are disrupting the dams' role in ensuring water security. The national freshwater reserve stands at 13 billion of m^3/y a figure that remains insufficient to achieve adequate water security. Projecting for 2060, an additional 2 billion of m^3/y must be added to the initial value for 35 years. To achieve this goal, Algeria must utilize its four water sources. Of the rainwater, only 7% of annual precipitation is used. 85% of the water returns to the sky as vapor. Storing rainwater underground is the only way to recover several billion cubic meters of water from the evaporated volume. The construction of hydraulic structures across the national hydrographic network, such as infiltration basins, sand dams, underground dams, recharge dams, and covered dams, must be expanded to create an innovative watershed management system that adapts to climate change. For effective water management, a new division of the national territory into eight hydrographic basins is essential.

Keywords: Water security, Watershed, Climate change, Sand dam, Underground dam, Water.

INTRODUCTION

Whether it's climate change, global warming, or climate disruption, even if the terminology differs, the consequences are the same: the climate is becoming unstable and water is becoming scarcer. In recent years, everyone has observed that the climate has indeed changed; prolonged droughts lasting four to six months are marked by high temperatures that can reach 45°C during August or July. Immediately following these periods of drought, torrential rains cause flash floods and, consequently, catastrophic flooding (Remini, 2023). This disrupted climate has detrimental consequences for a country's water resources. In this context, ensuring a country's water security becomes even more complicated. The countries most affected by this water-related climate are undoubtedly those in North Africa and the Mediterranean basin. With 450 m^3/y/inhabitant, the country is below the water stress threshold and risks seeing the situation deteriorate by 2030. Tunisia's conventional water potential is estimated at 4.8 billion of m^3/y, of which 55% is made up of surface water and 45% comes from groundwater (African Water Facility, 2016).

In Morocco, water scarcity due to climate change, population growth, and overconsumption has prompted the country to reassess its water management. Morocco has thus chosen to follow Algeria's lead by opting for seawater desalination. Morocco now has 17 desalination plants capable of generating nearly 350 million of m^3/y (Amghar and Hssoune, 2025). As for Libya, an arid country, its water resources are dwindling due to climate change. Despite average annual rainfall estimated at 98.5 billion of m^3/y, Libya is heavily dependent on fossil water sources, which are being depleted over time. Solutions such as desalination and network modernization are underway, but the water deficit is significant, exacerbated by climate change. In recent years, Libya has opted for the artificial replenishment of groundwater through the construction of recharge dams. Two dams are noteworthy: the Qattara Dam in Cyrenaica and the Kaam Dam in Tripolitania (Hamad, 2012). Regarding Mauritania, ensuring the country's water security is becoming a pressing challenge, complicated by climate change. Mauritania is one of the driest countries in the world, with some of the lowest water availability on the planet. More than 22% of the Mauritanian population lacks access to a basic source of drinking water, masking significant disparities within the country, and water stress is a daily reality for many communities (UNICEF, 2024).

Climate change is exacerbating this situation, leading to unpredictable rainfall patterns, prolonged droughts, and water resource degradation. Faced with this critical situation, Mauritania has launched initiatives to utilize all available water sources in the country to improve access to water for vulnerable populations. In a Mediterranean country like Spain, water security has become a major concern due to climate change, resulting in frequent droughts that severely impact dam levels. Following the seemingly endless heatwaves, where temperatures reached 46°C in El Granado, and the catastrophic floods that ravaged the city of Valencia in 2024, climate change is now a threat to Spain's water security (Martin-Moreno et al., 2025). Italy, another Mediterranean country, is also facing a major challenge in water security, impacted by climate change. Drought in Italy has gone from being an exceptional phenomenon to a chronic situation. The consequences for conventional water resources are detrimental: dried-up rivers, record low water levels in lakes, and depleted groundwater due to intensive exploitation. Faced with a shortage of conventional water, Italy has turned to non-conventional water sources, particularly wastewater from treatment plants (Guerrieri et al, 2025). As mentioned at the beginning of this introduction, ensuring water security in the era of climate change is a far more complex matter for Algeria. In the early 2000s, Algeria shifted from relying on dams to desalination plants. While national water security is satisfactory, it has not yet reached its optimum, meaning we are not immune to water shortages. In this context, we must consider our history of water management in oases, which offers valuable lessons. This paper offers some insights into how to utilize all the water resources available in Algeria.

MISSIONS TO THE SAHARA OASIS

Several working missions have been carried out in the Saharan oases since 1990. Investigations have been conducted at the sites of traditional hydraulic structures. Surveys have been carried out among the inhabitants of the ksour (fortified villages). Meetings have been organized with elderly farmers who possess impressive expertise in agriculture, architecture, and hydraulics. During this long period of 35 years (1990-2025), we visited all the oases of the Algerian Sahara, namely, the oases of the Mzab valley, the oases of the Souf valley, the oases of the Righ valley, the oases of the Saoura valley, the oases of Touat, Gourara and Tidikelt, the oases of Ziban, the oases of the Aurès, the oases of Metlili, the oases of El Guerrara, the oases of Ahaggar, the oases of Tassili N'ajjer, the oases of Berriane, the oases of Laghouat (Ain Madi and Tadjmout), the oases of Boussada, the oases of El Bayad (Sttiten, Boualem, Ghassoul, the Arbaouat, El Abiod Sidi Cheikh, Chellala, Assla, Brezina, Boussemghoun), the oases of Ain Sefra (Tiout, Sfissifa, Moghrar), the Tindouf oasis, and the Tabelbala oasis. These studies reveal that the Algerian Sahara is indeed a land rich in lessons regarding the architecture of the ksour (fortified villages), agriculture, and hydraulics. We can say that the Algerian Sahara remains an open-air laboratory concerning everything related to climate change. Regarding the sustainable management of water in the oases, there are many water capture and storage techniques that are well-suited to the arid climate. If there is a solution that can further increase the freshwater supply and consequently guarantee a very satisfactory national water security, it can only come from the Algerian Sahara.

Today, the world is turning to artificial recharge to replenish aquifers through the infiltration of flash floodwaters. However, for more than seven centuries, the farmers of the Mzab valley have practiced the artificial replenishment of the water table. Water security in the oases of the Mzab valley relies solely on artificial groundwater recharge during flash floods. A comprehensive hydro-agricultural system based on artificial groundwater recharge has been developed (Remini, 2021). It is equipped with recharge dams and wells. The practice of periodically flooding gardens with water as soon as flash floods occur is also employed. A rocky region with an arid climate, the Mzab valley experiences only one or two flash floods per year. In the oases of Ahaggar, Tindouf, and Sfissifa, the Inferoflux aquifer is exploited through foggaras (underground irrigation systems) installed in the hydrographic networks for over 10 centuries. In the Mzab valley, the Inferoflux aquifer is exploited through wells installed in the wadi beds. Underground dams were invented in the early 1940s for the exploitation of the Infroflux aquifer (Remini, 2021). In the oases of Ziban, Aurès, and Boussaâda, spring dams, a local invention, serve to store spring water (Remini, 2025a). However, with the drying up of these water sources, these dams have been converted into sand dams (Remini, 2025b).

Therefore, all these structures (recharge dams, underground dams, and sand dams) are currently being built in countries around the world to store rainfall.

RESULTS AND DISCUSSION

Water Security

Starting with the title of the article, "Climate Change: A Threat to Water Security," which comprises two key words: water security and climate change. We define a country's water security as the provision of water to the population and all socioeconomic sectors (agriculture, industry, mining, and energy) in a continuous and sustainable manner, both in quantity and quality, while safeguarding the environment. Such a mission becomes more complex in the context of climate change.

The Concept of Freshwater Stocks

To discuss water security, we must consider a country's freshwater stock (FWS), which is defined as the annual quantity of freshwater available within a country. In principle, this volume of water increases over time in line with population growth and the country's socioeconomic development. A country's freshwater reserves must meet the water demands of its various sectors (agriculture, domestic use, industry, mining, and energy) continuously and sustainably without harming the environment. In Algeria, we have estimated the annual freshwater reserves at over 13 billion m^3. This is a mix of natural and non-conventional water sources. The freshwater reserves consist of treated wastewater, desalinated water, reservoir water, fossil water, groundwater, foggaras water, and water stored in older structures (Table 1 and Fig. 1).

Table 1: Volumes of conventional and non-conventional water sources in the Algerian water supply system (Remini, 2025)

Water types	Volume (10^9 m^3/y)	Volume (%/y)
Dam watger	5,00	38 %
Fossil water	3,75	29 %
Groundwater	1,90	14 %
Desalinated water	1,35	10 %
Purified water	0,9	7 %
Water foggaras and other	0,3	2 %
Totals	**13,2**	**100%**

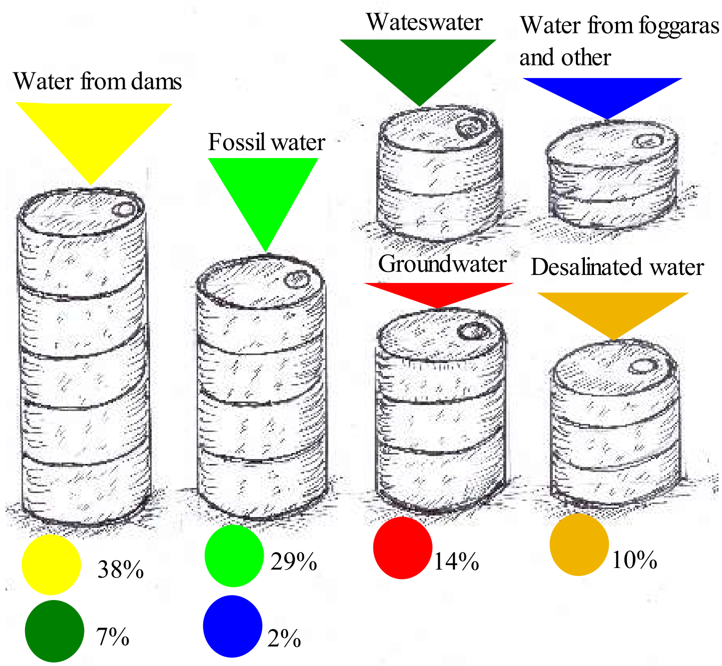


Figure 1: Algeria's freshwater reserves (FWR) estimated at 13 billion m³/y (Remini diagram, 2025)

However, considering Algeria's population, which is projected to reach approximately 47 million inhabitants in 2025, and the fact that the agricultural sector is a major water consumer, consuming over 70% of the total freshwater reserves, the development of the energy and industrial sectors also demands significant water resources. Furthermore, the mining sector, with its numerous deposit projects, particularly for iron ore, is also a significant factor. Given all these parameters, an initial estimate suggests that 20 billion m³/y would be needed by 2030 to achieve satisfactory water security. It is worth noting that accurately assessing the freshwater reserves is difficult due to a lack of data. However, according to Attar, a water capacity of 15 to 18 billion m³/y is required to mitigate water stress by 2030 (Messaoudi, 2023). A more accurate figure, but one that only considers drinking water supply and irrigation.

By 2060, Algeria's freshwater reserves will reach 80 billion m³/y for a population of 70 million (Meskine et al., 2025) (Fig. 2). Each year, approximately 2 billion m³/y will be needed to ensure Algeria's water security.

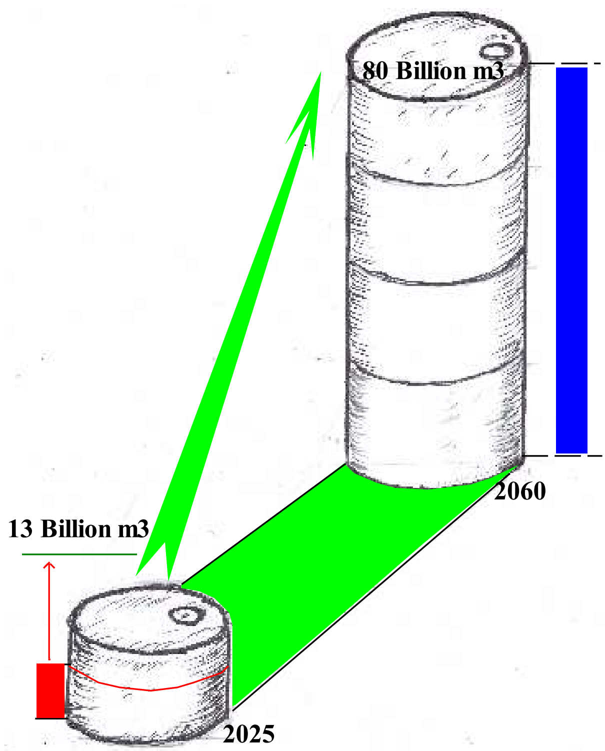


Figure 2: Forecast of freshwater stock in 2060 (Remini diagram, 2025)

So, in this case, what can be done to increase our freshwater reserves to support population growth and the country's socio-economic development in a disrupted climate by 2060? The answer to this need is to find an average of 2 billion m^3 of freshwater each year to reach a freshwater reserve equivalent to 80 billion m^3/y over 35 years. Providing 2 billion m^3 of water annually is no easy task. Such a situation necessitates a water revolution across the entire Algerian territory.

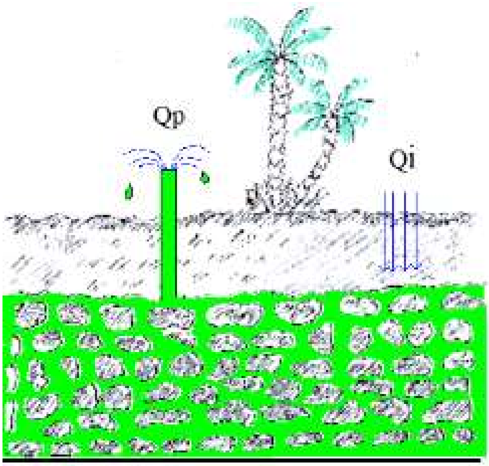
Today's Climate

Following this first section on freshwater reserves, we will now turn to the climate changes affecting our country. A new climate is taking hold in the Mediterranean basin, characterized by prolonged droughts marked by record temperatures, intense evaporation, and sometimes accompanied by forest fires. This long season is followed by a short-wet period marked by torrential rains that cause flash floods and, consequently, catastrophic and deadly flooding. These flash floods are simply Saharan floods that have moved northward into Africa and the countries of the Mediterranean basin (Remini, 2023). In addition to an impressive volume of water, these flash floods carry significant amounts of mud. The consequences of this new climate on water resources can be divided into two parts: direct and indirect consequences. The direct consequences affect dams and desalination plants, which are impacted by this disrupted climate. Dams are the primary victims of global warming, as they are affected by a double reduction in capacity: evaporation and siltation (Remini, 2024a) (Fig. 3).

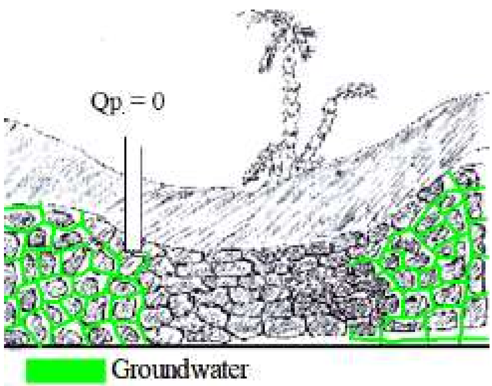
Figure 3: Boukourdane dam. For the second year, the dam is using its dead volume (Photo. Remini, 2025)

Desalination plants using the reverse osmosis process are not spared from the discharge of fine particles into the sea following flash floods. It should be noted that there are more than 50 wadis (seasonal watercourses) that flow into the 1600 km long coastline. The raw water intake of a desalination plant is contaminated by water laden with discharges from flash floods (Remini and Amitouche, 2023). Polluted, the raw water from desalination plants must undergo more rigorous and consequently much more expensive pretreatment. Obviously, the discharge of flash flood water into the coastline has a direct impact on reducing the lifespan of the reverse osmosis membranes. We are witnessing temporary shutdowns of desalination plants due to water laden with fine particles, discharged by flash floods that can reach the raw water intake area of the desalination plant. He indicated that this problem will worsen in the coming years due to the solid sediment carried by flash floods into the sea via more than 50 wadis (seasonal watercourses). It is important to remember that desalination plants using the reverse osmosis process require high-quality raw water, meaning seawater free of solid particles. Polluted raw water will further complicate the pretreatment phase and reduce the lifespan of the membranes, consequently increasing the price per cubic meter of desalinated water. Therefore, choosing the location for the water intake becomes a crucial step in any seawater desalination plant project (Remini and Amitouche, 2023).

Regarding the indirect consequences of climate change on freshwater stocks, once dams no longer fulfill their role in water storage, recent years have seen significant pressure on the intensive exploitation of groundwater through the proliferation of boreholes. This has led to the depletion and drying up of groundwater (Fig. 4); a complex and irreversible phenomenon (Remini, 2023).



(a)



(b)

Figure 4: Approximate diagram of the groundwater depletion process (Remini diagram, 2025b); a) Infiltration less than warter sampling; b) Soil subsidence

The groundwater reserves of northern Algeria, with a capacity of 2 billion of m^3, have been exploited for over 20 years at a rate of 1.9 billion of m^3 /y. These natural underground reservoirs are 95% utilized, meaning that natural infiltration equals withdrawals. This situation exposes these aquifers in northern Algeria to irreversible subsidence of the ground, and consequently, there is a risk of permanently losing a significant volume of these reservoirs. Regarding the coastal regions, the lowering of the water table following intensive withdrawals during periods of drought has caused seawater intrusion into the coastal aquifers. A saltwater wedge flows as a density current in the groundwater (Fig.

5). This northward flow pollutes the freshwater, turning it into saltwater. A similar situation is developing along the 1600 km long Algerian coast.

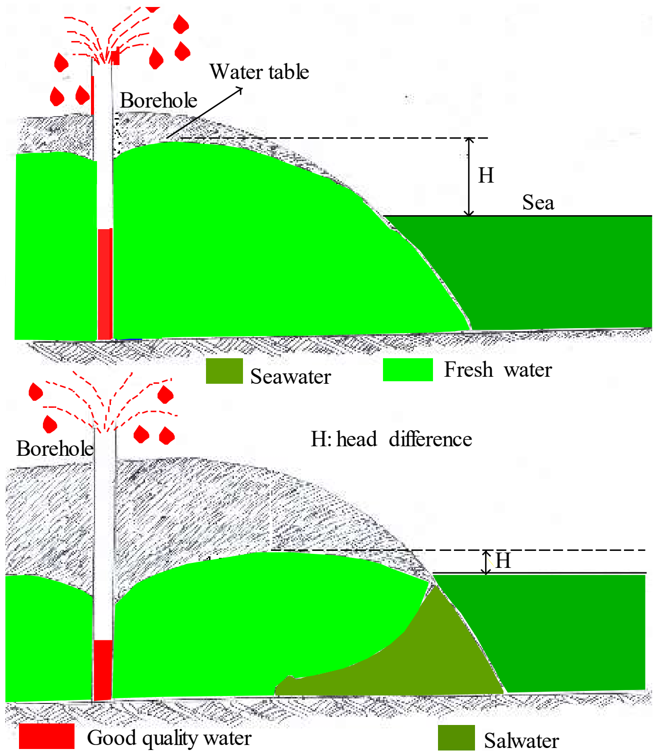


Figure 5: Intrusion of seawater into coastal aquifers (Remini diagram, 2025b)

Flash floods, which are simply the floods of the Sahara, have moved northward into Algeria and even into the Mediterranean basin. These new floods are characterized by a significant influx of water, as these flash floods discharge a substantial amount of water equivalent to four to six months of rainfall in just a few hours. We observed that the flash flood that occurred in Algiers (Bab El Oued) on October 9th and 10th, 2001, with a flow rate of 730 m^3/s, carried a volume of 1.5 million m^3 of mud. The flash flood that occurred on the Mzab River on October 1st, 2008, resulted in a flow rate of 1200 m^3/s. This figure was determined based on historical records of the flood's flow. What impressed us most was the amount of mud carried by the flood, which we estimated at 0.6 million m^3. The flood of October 28-31, 2011, occurred on the Labiod wadi, a flood of rare violence with a peak flow rate estimated at over 1600 m^3/s. More than 1.5 million m^3 of mud were stored in the dam. The sheer quantity of mud brought by this flash flood is impressive; a characteristic of flash floods. Saharan floods carry both water and mud. The question that arises today is: where does all this mud come from? Quite simply, these quantities of mud are the result of erosion, a phenomenon that is accelerating with climate change. During the long dry season, which lasts for 5 to 7 months, temperatures can reach 40°C. Indeed, the soil becomes vulnerable to erosion, easily detached and transported by runoff, which dislodges these solid particles, thus diminishing its structure and fertility. This prolonged dry period ends with a short-wet period marked by flash floods. Torrential rains, equivalent to five to six months of precipitation, fall in just a few hours on soil conducive to particle detachment. Such a situation accelerates soil erosion and promotes the formation of new gullies (Fig. 6).

Figure 6: A view of the El Hammam River watershed (Photo. Remini, 2025)

A new phenomenon is emerging: a resizing of the North African hydrographic network. We are currently in a transitional phase. The Mediterranean climate is shifting towards a Saharan climate. This is referred to as Saharanization. The wadis of North Africa and the countries of the Mediterranean basin are widening to accommodate the significant volume of water brought on by torrential rains (Fig. 7).

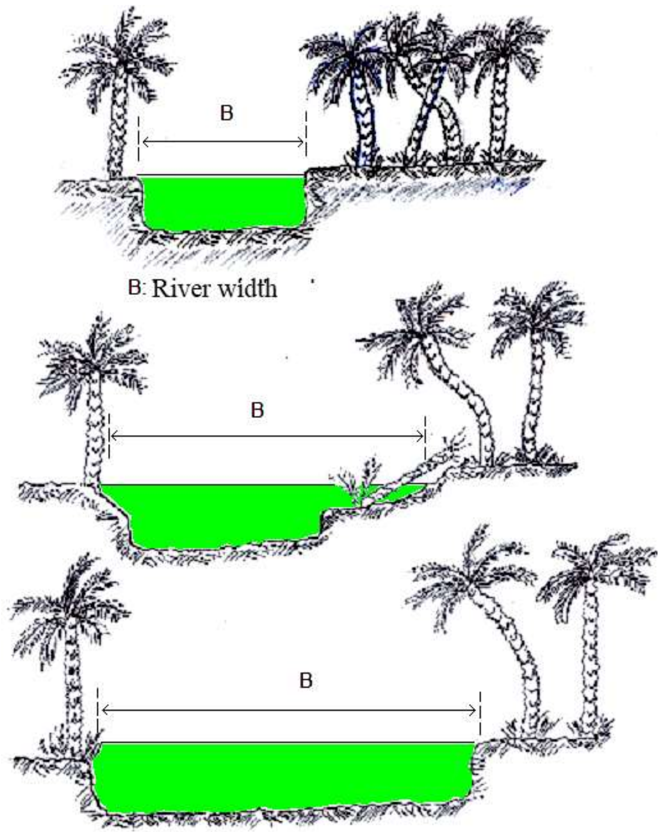


Figure 7: Approximate diagram of River widening (Remini, 2023).

The phenomenon of bank erosion becomes much more significant following flash floods in the wadis. Flood after flood, the banks erode until the required cross-section is reached. Unlike the wadis of northern Algeria, which have small cross-sections, the wadis of the Sahara have wide cross-sections, even exceeding one kilometer in width. For example, the Cheliff River, one of the largest wadis in Algeria, is undergoing a widening of its cross-section (Fig. 8).

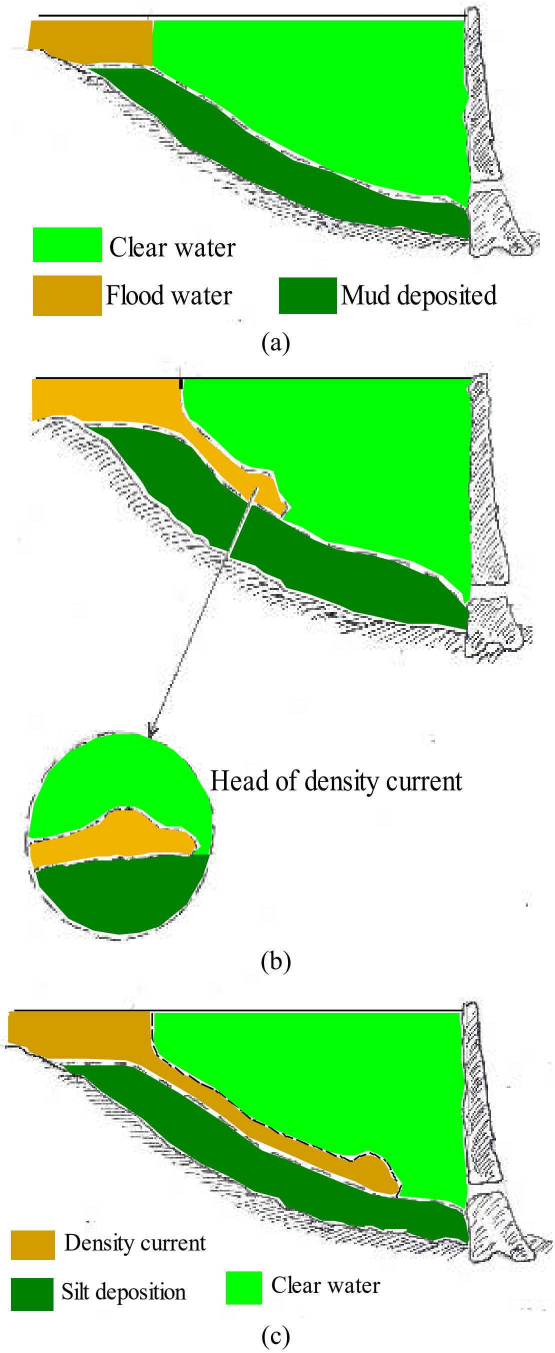
The deepening of old gullies, the formation of new gullies, and the undermining of riverbanks produce significant quantities of mud. These sediments, with concentrations of 100 g/l, reach the wadis, where the concentration of fine particles generally exceeds 100 g/l. These floods, laden with fine particles, come into contact with the clear water of the dam, creating density currents that propagate across the dam floor as a mixing sheet, reaching the dam's base and causing siltation (Figs. 9 and 10). Of the 83 dams in operation with an initial capacity of 8.5 billion m^3, 2 billion m^3 of mud have been deposited at the bottom of these dams (Remini, 2017b) (Fig. 11).

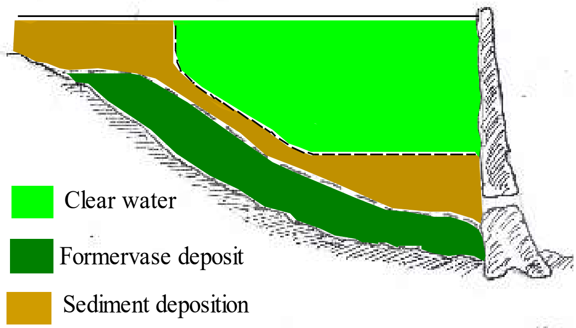
Figure 8: In recent years, the Chelif River has widened (Photo. Remini, 2013)

a) Contact of salt water with fresh water

b) Propagation of the density current

Figure 9: Propagation of a density current in a laboratory channel (Photo. Remini 2008).


Clear water
Flood water
Mud deposited
(a)
Head of density current
(b)
Density current
Silt deposition
Clear water
(c)



(d)

Figure 10: Siltation process of a dam in an arid environment (Remini diagram, 2025); a) Arrival of the flood; b) Formation of the density current; c) Propagation of the density current; d) Mud deposition

Figure 11: Fergoug Dam silted up to more than 90% of its capacity (Photo. Remini, 2009)

During both dry and wet seasons of a hydrological year in a climate of erratic conditions, the dam suffers a double loss of capacity: evaporation and siltation. The second victim of this climate is the seawater desalination plant. The 18 operational desalination plants are built along the Algerian coast over a length of 1,600 km. Seventeen of these plants are equipped with a reverse osmosis process. This type of process requires high-quality raw water (seawater). However, today more than 50 wadis discharge tons of solid particles along the Algerian coast. It is estimated that these wadis release an average of 120 million tons into the Mediterranean Sea each year (Demmak, 1982). With these new floods, this value, the solid mass, will be multiplied by 2 or 3. These enormous quantities of fine particles invade the raw water intake sites of desalination plants. This problem complicates the raw water treatment process, resulting in a more expensive pretreatment phase and a reduced lifespan for the reverse osmosis membranes. The efficiency of desalination plants depends on the correct choice of raw water intake site. However, during periods of flooding, many desalination plants prefer to temporarily halt the desalination process to avoid the intake of water laden with fine particles. These repeated shutdowns of the desalination process during flash floods directly impact the efficiency of the seawater desalination plant.

- **What can be done to increase freshwater reserves and thus ensure Algeria's water security?**

The climate is changing, water is becoming scarce, what can be done? Answering this question definitively is complex. Every drop of water that falls on Algeria's 2.38 million km² territory is crucial. A close examination of Algeria's main water sources reveals that the seawater source, identified in the early 2000s, is now the most reliable source for supplying Algeria with drinking water. Seawater desalination alone will never be able to meet the growing water demands of the population and the socioeconomic sectors (agriculture, industry, mining, and energy), which are expected to reach 2060. In this case, a freshwater reserve of 80 billion m³/y would be required (Meskine et al., 2025). All four of Algeria's water sources must work together to achieve our goal of a freshwater reserve of 80 billion m³/y. To increase our freshwater reserves and thus ensure Algeria's water security in the era of climate change, we simply need to utilize all four of Algeria's water sources. Not a drop of water is wasted; a water revolution is essential! Algeria has four main water sources. These are the following (Fig. 12): (1) Rainwater, (2) Seawater, (3) Wastewater, and (4) Fossil water.

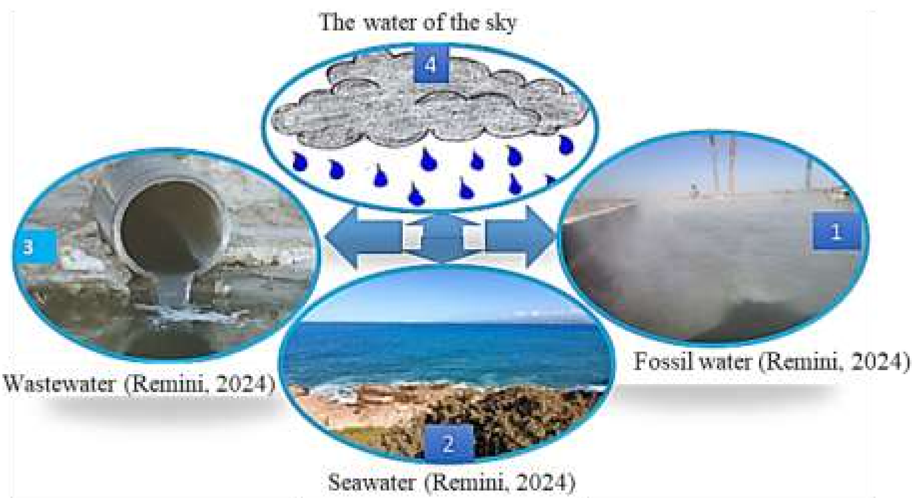


Figure 12: Algeria's 4 Water Sources (Photos. Remini, 2024)

Fossil Water

Fossil water is rainwater stored in deep aquifers for centuries. It is a non-renewable or nearly renewable resource. Indeed, a hidden treasure of blue gold lies in the Algerian subsoil, little known and poorly assessed. Algeria possesses an underground sea of fresh water with a volume of over 80 trillion m³, covering a water surface of approximately 1.3 million km², representing 54% of the national territory (Remini, 2025c). Algeria shares six transboundary aquifers with its neighbors, three of which are classified as major aquifers (Table 2 and Fig. 13).

Table 2: Characteristics of transboundary aquifers in Algeria (Remini, 2025c)

N°	Aquifer system	Volume km³	Area 10³ km²	Shared countries
1	Northern Sahara	60 000	1000	Algeria, Tunisia, Libya
2	Taoudéni/Tanezrouft/ Iullemeden	15 000	2500	Algeria, Nigeria, Niger, Burkina Faso, Benin, Mali, Mauritania
5	Mourzouk	4 800	450	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

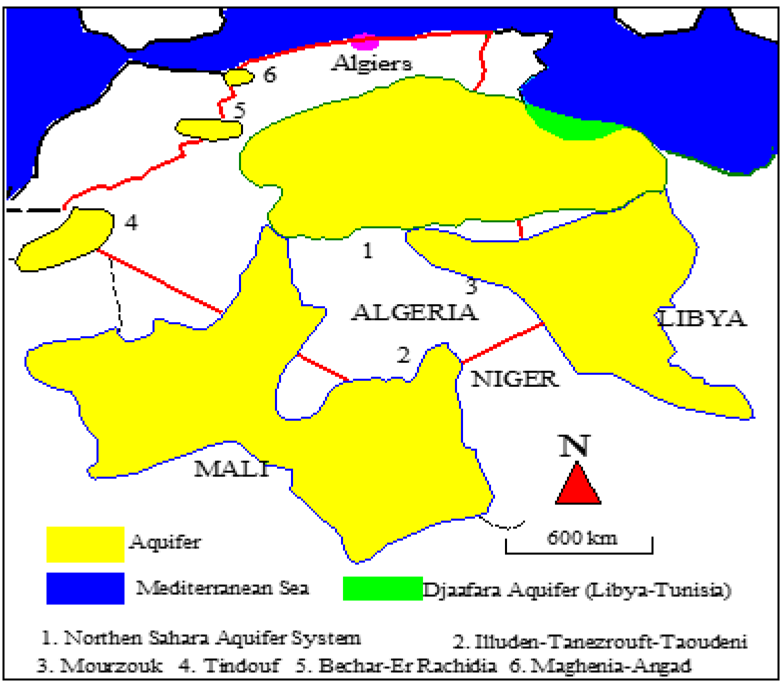


Figure 13: The 6 major transboundary aquifers with Algeria (Remini 2024b; Remini, 2025c)

Fossil water is a reliable source in Algeria, with an estimated 80 trillion m³ hidden underground. Currently, this vast water deposit is being exploited at a rate of 3.75 billion m³/y, particularly from the Northern Sahara Aquifer System (NSAS). This aquifer system, composed of two superimposed aquifers: the Continental Intercalaire and the Terminal Complex is the only water reserve being properly exploited (Fig. 14). For a long time, the aquifers of the Northern Sahara Aquifer System were considered fossil, meaning they were not replenished. Today, the Northern Sahara Aquifer System is replenished by rainfall. Each year, approximately 1.5 billion m^3 of water seep into the Sahara's subsoil to fill the vast aquifer of the Northern Sahara. During the period 2003-2010, annual recharge reached 4.5 billion m^3 (Gonçalves, 2013). In our opinion, the Northern Sahara Aquifer System was fully recharged in October 2008; an exceptional year when all the wadis were in flood, namely the Saoura, the Mzab, Mettlili, Nssa, Ain Sefra, Namous, Mzi, and all the smaller wadis of southwestern Algeria.

Figure 14: Touggourt, Albian borehole over 1800 m deep (Photo. Remini, 2023).

However, a serious study on the impact of water withdrawals on groundwater depletion is essential. The number and location of deep boreholes must be examined. It is time to study the Taoudéni/Tanezrouft/ Iullemeden aquifer system (TTIAS) to begin its exploitation. Algeria possesses a significant share of this "blue gold" deposit. Seven countries (Algeria, Nigeria, Niger, Burkina Faso, Benin, Mali, and Mauritania) share a water reserve covering an area of 2.5 million km², making the Taoudéni/Tanezrouft/Iullemeden Aquifer System the second largest aquifer on the African continent after the Nubian Sandstone aquifer system (2.6 million km²). The Taoudéni/Tanezrouft/ Iullemeden Aquifer System (TTIAS) can supply 19 billion m³/y (11 billion m³/year from the Taoudéni/Tanezrouft basin and 8 billion m³/y from the Iulleden basin). Only 350 million m^3 (less than 2%) are extracted annually (Observatory of the Sahara and Sahel, 2017). However, the Northern Sahara Aquifer System can supply 10 billion m³/y, but withdrawals for the three countries (Algeria, Morocco, and Tunisia) have reached 5 billion m³/y. The Taoudéni/Tanezrouft/ Iullemeden Aquifer System (TTIAS)) is recharged by the Niger River with a flow rate of 4.8 billion m³/y. It is time for Algeria to begin exploiting the Taoudéni/Tanezrouft/Iullemeden aquifer system, as Algeria occupies 451,000 km² of this underground sea, representing 17% of the aquifer's total area (Remini, 2025c).

In the early 1970s, this aquifer system was considered a fossil water table; a non-renewable aquifer. However, today it appears that these aquifers are replenished with 1.5 billion m³/y, thus transitioning from non-renewable to low-renewable.

Seawater

With a coastline of over 1,600 km, Algeria has the potential to build hundreds of seawater desalination plants. Having access to the sea is a blessing, as it represents an inexhaustible source of water. However, the salt must be removed. Two desalination processes have been used in Algeria. Of the 18 operational seawater desalination plants, 18 use membrane processes (reverse osmosis) and (1) use thermal processes (distillation). These 18 plants produce a volume of drinking water equivalent to 3.7 million m³/day, or 1.35 billion m³/y. Regarding the source of seawater desalination, the Algerian state has made remarkable progress over the last 20 years. The seawater desalination plant is beginning to replace the reservoir dam, the flagship project of the 1980s.

Wastewater

There are three types of wastewaters. These include urban wastewater (sewage treatment). Approximately 210 wastewater treatment plants are in operation throughout Algeria, producing a total of 0.9 billion m³ of treated water. This figure is considered insufficient. The source of wastewater lags far behind the other three sources. These volumes of treated water are discharged directly into wadis (riverbeds). Air-laden lagooning plants have been built in major cities in southern Algeria; the treated water produced is discharged into chotts (salt lakes) (Fig. 15).

Figure 15: Souf valley Lagoon Wastewater Treatment Plant (Photo. Remini, 2024)

This is a significant step forward, as pollution of the salt lakes (chotts) is steadily decreasing. Even migratory birds are returning to their usual locations (chotts). Other wastewater treatment plants are planned for the coming years. The water services must now move to the second stage: the reuse of treated wastewater in agriculture. The third stage involves artificially replenishing groundwater with treated water.

Regarding industrial wastewater, there is no in-depth study on the exploitation of this water source, which will become a considerable quantity in the coming years. As for runoff from plants (drainage water), its treatment has never been the subject of a thorough scientific study. It is time to address this issue. A significant amount of drainage water from the palm groves in the Algerian Sahara always flows into the chotts and ergs. For example, the Oued Righ canal discharges an average flow of 220 million m^3/y into the Chott Merouane each year (Figs. 16 and 17).

Figure 16: Canal carrying drainage water from the palm groves of Touggourt (Photo. Remini, 2023)

Figure 17: Discharge of drainage water from the Tolga palm groves into the Djeddi River (Photo. Remini, 2024)

Rainwater Harvesting

To avoid a water shortage and ensure Algeria's water security in the coming years, relying solely on seawater desalination will not definitively solve the water security problem. Therefore, harnessing rainwater harvesting becomes essential. Rainfall in northern Algeria has been estimated at 100 billion m³/y (Demmak, 1982). We obtained the same figure as Demmak in 1982. Our study also yielded the same quantity of 100 billion m³ for the Algerian Sahara. This brings the total annual rainfall across Algeria to 200 billion m³. It is worth noting that in northern Algeria, of the 100 billion m³/y of rainfall, only 7 billion m³/y are exploited, with 5 billion m³/y coming from the 83 dams currently in operation. Annual groundwater withdrawals in northern Algeria have been estimated at 2 billion m³. This represents only 7% of annual rainfall consumption. Table 3 illustrates the low annual volume of rainfall utilized by North African countries.

Table 3: Water resource potential from rainfall in North African countries

Country	Precipitation (10^9 m³/y)	Water resource potential (10^9 m³/y)
Algeria (North)	100	7
Morocco	140	22
Tunisia	36	4,8
Libya	98,5	29

Based on all these values, the diagram in Fig. 18 clearly illustrates the total water balance of northern Algeria.

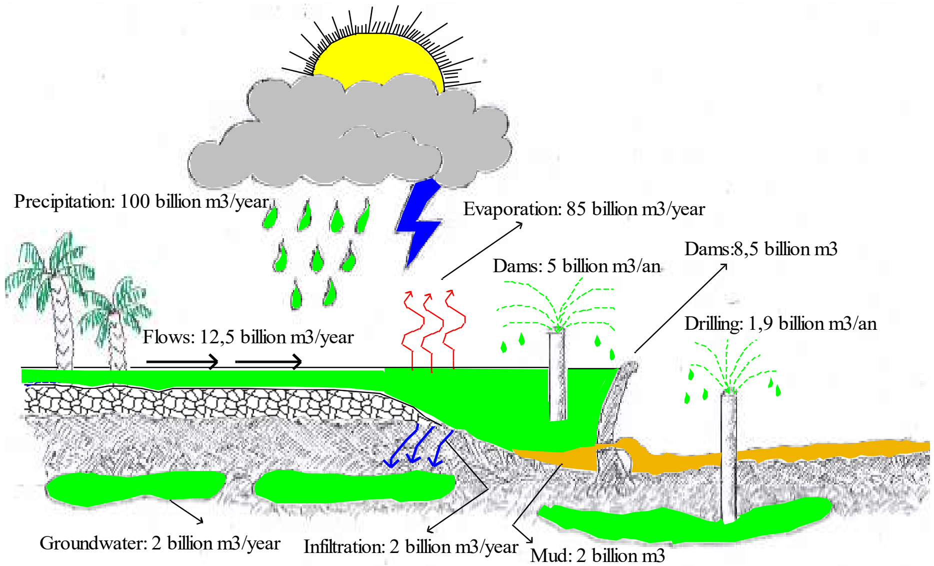


Figure 18: Water balance in northern Algeria (Remini diagram, 2025)

Regarding rainfall in southern Algeria, which corresponds to the Algerian Sahara, there is no information or data on groundwater withdrawals or surface water use. With climate change affecting Algeria, evaporation in northern Algeria is around 85 billion m^3/y; a high value compared to the 100 billion m^3 that fall from the sky. In southern Algeria, evaporation is much higher, reaching 3 m^3/y. As for rainfall, Algeria receives approximately 200 billion m^3/y from the sky. In northern Algeria, which receives 100 billion m^3/y of rainfall annually, 85 billion m^3/y returns to the sky as vapor. So how can we recover the billions of cubic meters of water that evaporate into the atmosphere? Two solutions are proposed: recovering the water in the form of vapor or storing rainwater in underground reservoirs, protected from evaporation. Currently, the first solution, vapor recovery, is not feasible. However, storing rainwater underground to minimize evaporation seems the most practical option. This solution requires the construction of hydraulic structures that promote rainwater infiltration at the expense of evaporation. Recharging groundwater and alluvial aquifers is the best solution in a climate of climate change. To this end, we have proposed six hydraulic structures for construction. The choice of location for each structure depends on the geological and hydrogeological conditions of the environment. Water harvesting techniques adapted to climate change are as follows (Remini, 2025b): (1) Sand dam, (2) Underground dam, (3) Recharge dam, (4) Mixed dam (underground ans surface), (5) Covered dam (Djoub), zand (6) Infiltration bassins.

Sand dam

A sand dam is constructed on the wadi bed, similar to a conventional or surface dam. The concept of the sand dam originated from spring dams. These dams are filled by spring water and temporarily by flash floods. They are initially filled by the gravel carried by the floods. Over time, the water becomes trapped between the gravel. In this case, the water is protected from evaporation and can withstand one to two years of drought. A single flash flood is enough to fill all the cracks in the rocks and the gaps between the pebbles deposited in the dam (Figs. 19 and 20).

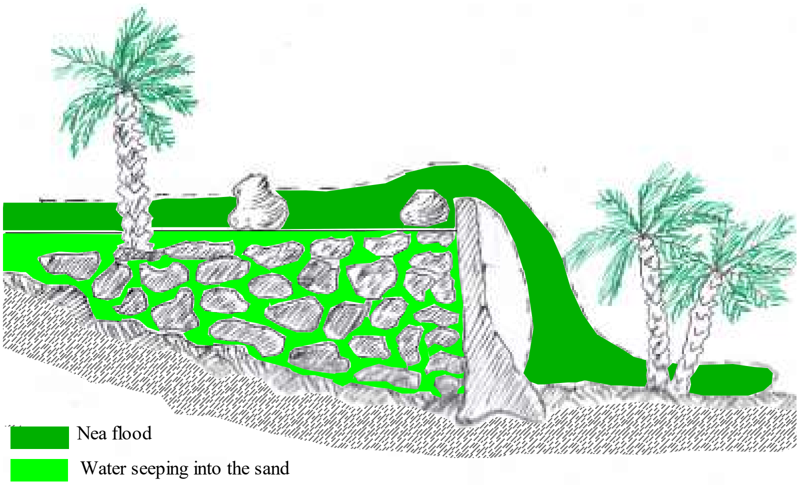


Figure 19: Probable diagram of a sand dam (Remini diagram, 2025)

Figure 20: Some existing dams on the Abiod River (Photo. Remini, 2025)

For centuries, the water sources emanating from the wadi's bed and banks dried up due to climate change. With the springs drying up, these spring dams became sand dams. Today, this type of dam is making a strong comeback and is becoming the hydraulic structure for adapting to this disrupted climate. In an initial study, we identified 26 countries with this type of hydraulic structure, estimated at over 3,000 sand dams built worldwide in recent years. Kenya alone has more than 1,500 sand dams (Remini, 2025b). Algeria lags far behind. What can be done today to capture the flash floodwaters drained by the more than 150 Rivers existing within Algerian territory? Wadis exceeding 300 km in length lack a single sand dam. It is time to consider constructing these small dams throughout the entire Algerian hydrographic network. Ideally, a series of cascading dams should be built to store a large quantity of water.

To maximize the volume of water infiltrated into the sand and aggregates trapped by the sand dams, it would be advantageous to construct several dams in cascade or in series along sections of the wadis (Fig. 21).

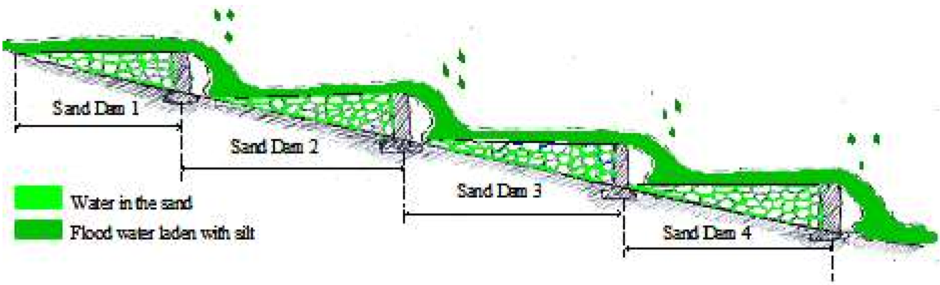


Figure 21: Approximate diagram of sand dams in series (Remini diagram, 2025)

It is true that no hydraulic structure can match the surface dam in terms of water quantity. However, sand dams and underground dams store a small quantity of water, but of much higher quality than surface dams. The volume of water contained between the cracks and voids between the aggregates is estimated at approximately 30% of the volume of a surface dam (fig. 22).

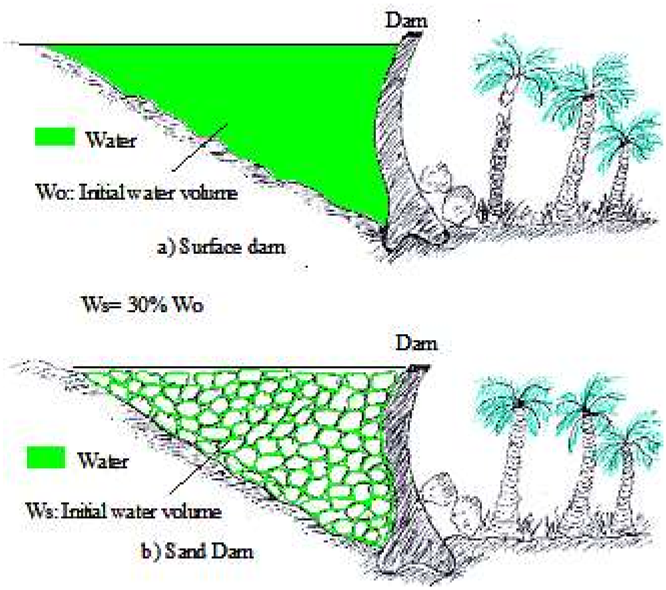


Figure 22: Approximate diagram of sand dams in series (Remini diagram, 2025)

The construction of a sand dam is a delicate balancing act between climate and human intervention. This type of dam project is carried out over several seasons. The dam's embankment, approximately 1 to 2 meters high, is built during the first dry season. The first flash flood, occurring immediately after the drought, carries a volume of aggregate that is deposited behind the first wall, 1 to 2 meters high. During the second dry season, the embankment is raised by 1 to 2 meters, and the next flash flood is expected to deposit a second quantity of sand, and so on until the project is completed (fig. 23).

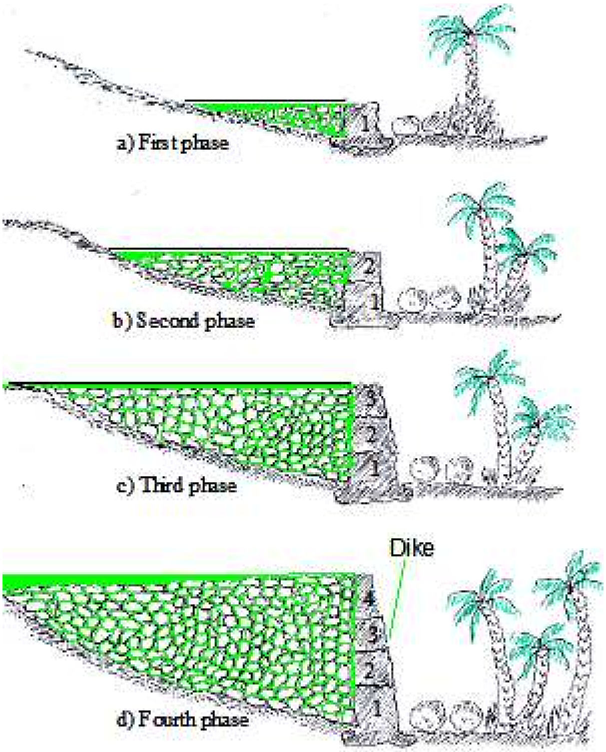


Figure 23: Approximate diagram of the construction stages of a sand dam (Remini diagram, 2025)

Underground dam - Inferior flow dam

Unlike a sand dam, which resembles a shallow aquifer, an underground dam stores water underground. Today's climate is suitable for this type of structure. The current priority is to build these types of dams throughout the entire hydrographic network. The underground dam is constructed underground above the wadi bed to utilize the inferior flow (alluvial) aquifer (fig. 24).

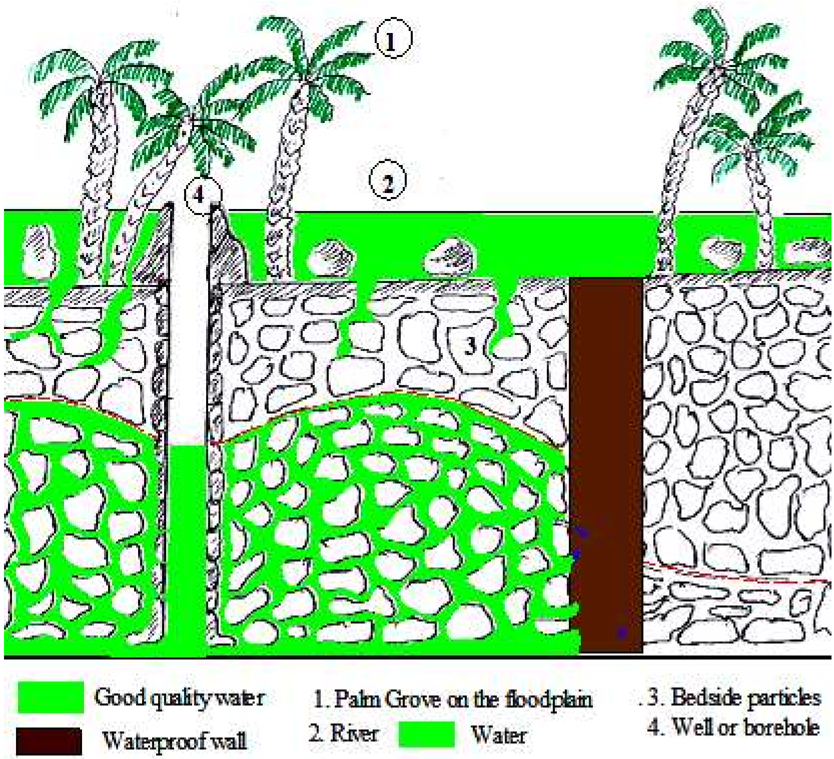


Figure 24: Approximate diagram of an Inferoflux dam (Remini diagram, 2025)

The high-quality alluvial aquifer has been used for centuries by farmers to supply drinking water to the ksar (farmers' dwellings) and to irrigate the palm groves of the oases. It is thanks to the foggaras system that the water from the subsurface aquifer is channeled to the gardens (Remini, 2020). It was from these foggaras that the idea of underground dams for exploiting the subsurface aquifer arose. One of the first underground dams in the world was built in Algeria, specifically in Laghouat on the Mzi River: the Tadjmout subsurface dam, constructed in the early 1940s. The dam was built to retain the flow of the alluvial aquifer beneath the riverbed. The Tadjmout dam on the Mzi River was commissioned in 1949. Its projected flow rate was 1 m^3/s, irrigating an area of 3,000 hectares (René, 1985).

The Mzi River forms the upper reaches of the Djedi River. This entire hydraulic network, from its source in the Djebel Amour to its mouth in the Chott Melrhir, reaches a total length of approximately 480 km and constitutes the Djedi River. It originates in the Saharan Atlas Mountains, south of the Djebel Ammor (near Aflou), at an altitude of approximately 1,400 meters. It flows from west to east through the wilayas of Laghouat, Ouled Djellal, and Biskra. It empties into the Chott Melrhir, the lowest point in Algeria. Its lowest point can reach an altitude of -35 to -40 meters. On a watercourse as long as the Djedi River, only one underground dam has been built, at Tadjmout, named after the oasis located on the Mzi River, a section upstream of the Djedi River. Today, groundwater exploitation is carried out using underground dams in the wilayas of Adrar, Tamanrasset, Bayadh, Illizi, and Laghouat. With nine dams in total, the stored capacity is approximately 30 million m^3. The wilaya of Tamanrasset has five dams; an insufficient number, but this should be increased and implemented throughout the entire country, not just in the Saharan regions (Remini, 2020). Globally, the priority today is to increase the number of underground dams. This is why more than 24 countries worldwide possess this type of hydraulic structure. Brazil alone has over 500 dams.

As we emphasized earlier in this article, with a disrupted climate, dams are the first victims of this climate, becoming unable to meet the demands for irrigation and drinking water. This situation has led water management services to intensively exploit groundwater. Boreholes and wells have proliferated across Algeria to meet all water demands. This situation has caused a significant drop in the water table. In coastal regions, this drop in the water table has led to the phenomenon of saltwater intrusion into coastal aquifers. Today, the entire Algerian coast is threatened by this phenomenon. There are two solutions to mitigate saltwater intrusion. The options are to replenish the coastal aquifer with fresh water or to construct an underground dam. The Inferoflux dam solution remains a safer option than artificial aquifer recharge (fig. 25).

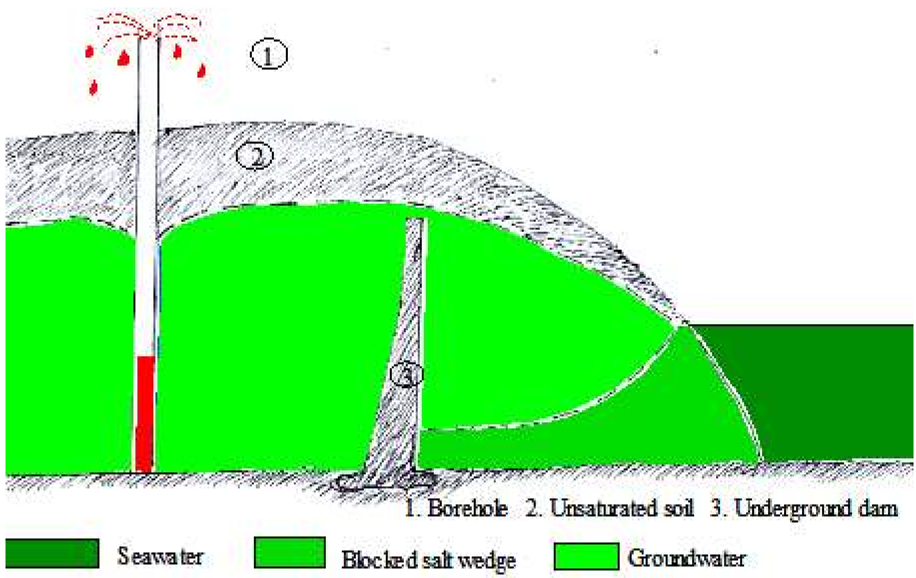


Figure 25: Diagram of a solution to stop the spread of saltwater intrusion: the underground dam (Remini diagram, 2025)

Recharge dam

The groundwater recharge dam is a local invention used for over seven centuries in the Mzab valley (Algeria) (Figs. 26 and 27). Today's climate necessitates the construction and expansion of recharge dams and the avoidance of hillside reservoirs. These latter reservoirs are no longer viable in this climate, as their water evaporates in a single dry season and can be washed away or completely silted up by a single flash flood. It is simply a matter of choosing a site that promotes infiltration into the subsoil, i.e., permeable soil. Algeria should adopt this type of structure and extend its construction throughout the entire hydrographic network.

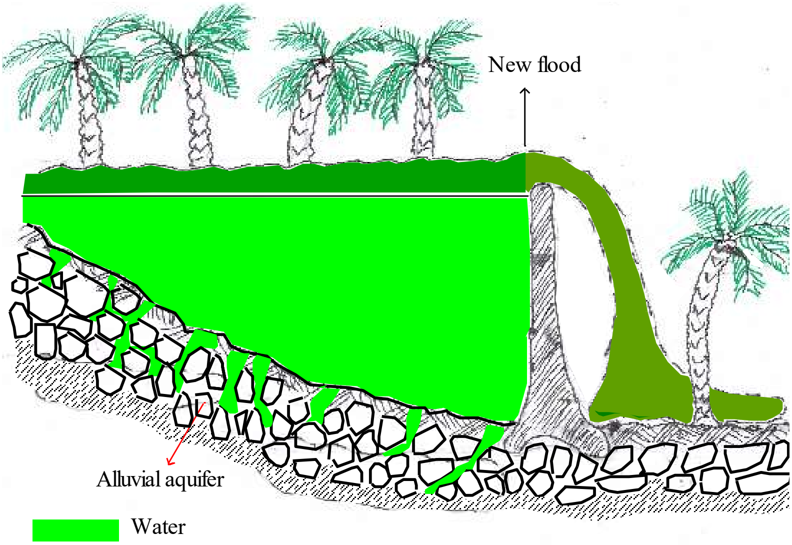


Figure 26: Probable design of a recharge dam (Remini diagram 2025)

Figure 27: A view of the large dam (Ahbas) at Beni Izguen (Photo. Remini, 2006)

Covered Dam (Djoub)

Called the Djoub, this covered dam, of Algerian origin, is a type of dam built within the hydrographic network of the Algerian Sahara over several centuries. Constructed with rock and gypsum mortar, the covered dam is used for watering livestock and camels (Fig. 28). Without a dike, the Djoub is a rectangular or circular reservoir buried at the bottom of the wadi bed to prevent it from being swept away by flash floods (Remini, 2019). The Djoub is equipped with ancillary structures such as openings placed at the same level as the wadi bed to allow for adequate filling of the reservoir. A rectangular channel connects the small well (attached to the large buried reservoir) and the small rectangular basin for the livestock. The covered dam, a typical feature of Algeria, is designed to store flash floodwaters. The water is protected from evaporation. Our hope is to see this type of covered dam become widespread throughout Algeria's river systems.

Figure 28: An overview of the covered dam in the El Guerrara region (Photo. Remini, 2009)

The combined dam (Surface and Underground Dam)

Why not combine the two existing dams into a single hydraulic structure: the underground dam and the surface (conventional) dam? Such a structure can store groundwater from the subsurface aquifer and surface water in the surface reservoir (Fig. 29).

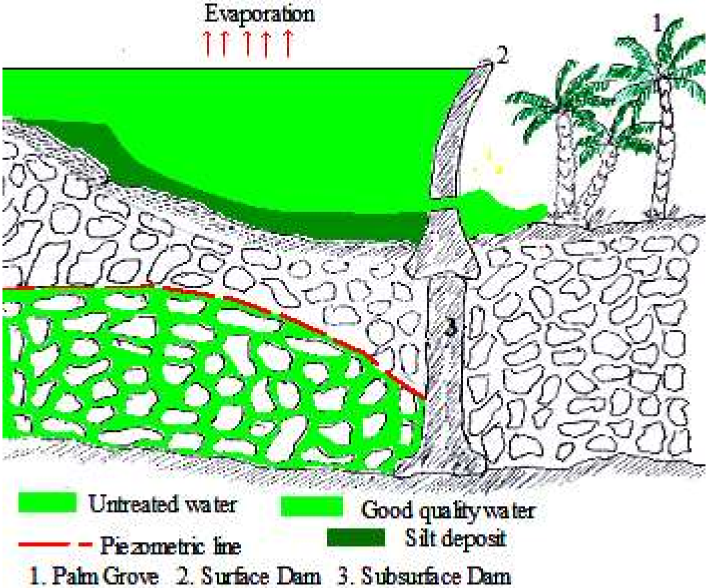


Figure 29: Approximate diagram of a mixed (underground and surface) dam (Remini diagram, 2025)

This dam does indeed exist in Algeria; it is called the Mefrouch dam (Remini, 2025c). The surface reservoir, with a capacity of 15 million m³, was filled in 1963. Its catchment area covers 86 km² and is drained by the 14 km long En-Nachef River. It is perhaps the only dam of its kind in the world. It is a structure well-suited to this unstable climate. It would be beneficial if this type of dam were generalized and built across the entire national hydrographic network, but of course, the ideal site for its construction must be found.

Infiltration basins

Climate change has created a conflict between evaporation and infiltration. Once rainwater reaches the ground surface, it has three paths to take: a horizontal path following the slope towards a depression (sea, chott, sebkha), a vertical path with two directions: upwards, where the water evaporates, and downwards, where the water infiltrates the subsoil. 85% of precipitation evaporates; the water prefers to return to its source. Therefore, it is necessary to encourage water infiltration into the subsoil. In this case, the ideal site must be found that facilitates water infiltration to replenish the water table. Soil with good permeability is the best site for constructing groundwater recharge basins. Ideally, a recharge station should be equipped with at least two basins. The first will ensure the settling of fine particles and the second will be used to recharge the water table (Figs. 30 and 31).

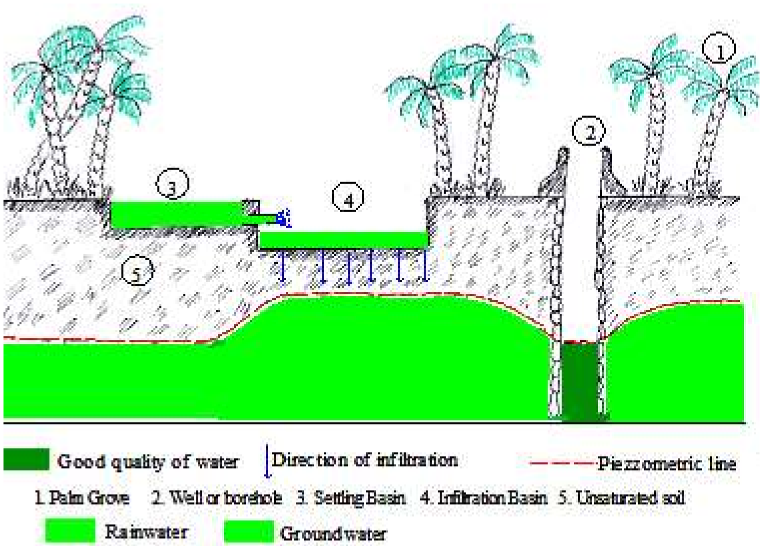


Figure 30: Approximate diagram of the infiltration basins (Remini diagram, 2025)

Figure 31: Infiltration basins of Bouinan (Blida) (Remini, 2025b)

These infiltration basins must be dug near a watercourse, depending on the availability of a suitable site with high permeability. A irrigation canal (seguia) is dug, starting from the wadi (riverbed) and flowing directly into the first basin, which serves for sediment settling. The clear water, via a connection, flows directly into the second basin, which is used for aquifer recharge. In Algeria, recharge basins were constructed in the early 2000s in the municipality of Bouinan in the wilaya (province) of Blida. This station was designed to recharge the Mitidja aquifer with water from the El Harrach River. At the time, this artificial aquifer recharge yielded very good results, as the water level in wells rose within a 20 km radius. Today, this aquifer recharge system has been abandoned, and Algeria has no artificial aquifer recharge stations. It is time to build and increase the number of infiltration basins throughout Algeria.

Other techniques for artificially recharging groundwater

It must be understood that every drop of water that falls on Algerian soil must be absorbed underground. In addition to the artificial recharge techniques mentioned previously, we recommend other adaptation techniques to recharge groundwater and gain thousands of cubic meters of fresh water.

Flooding Gardens

A technique originating in oases, flooding gardens is a practice applied in wadi oases. For example, this technique is applied in the oases located along the Rivers of Mzab (Ghardaia), N’ssa (Beni Isguen), Zegurir (El Guerara), and Abdi (Biskra and Batna). Beyond its economic benefits, the water brought by flash floods is shared among the farmers. Each farmer's share is based on the number of palm trees and their individual contribution to the maintenance of the palm grove. In the wadi oases, the spring dams fill up, but once the wadi floods, the irrigation channels remain open during the flood's arrival. This excellent method of flooding the gardens has a dual benefit: the deposition of fine particles, which acts as a natural fertilizer, and the artificial recharge of the water table (Fig. 32).

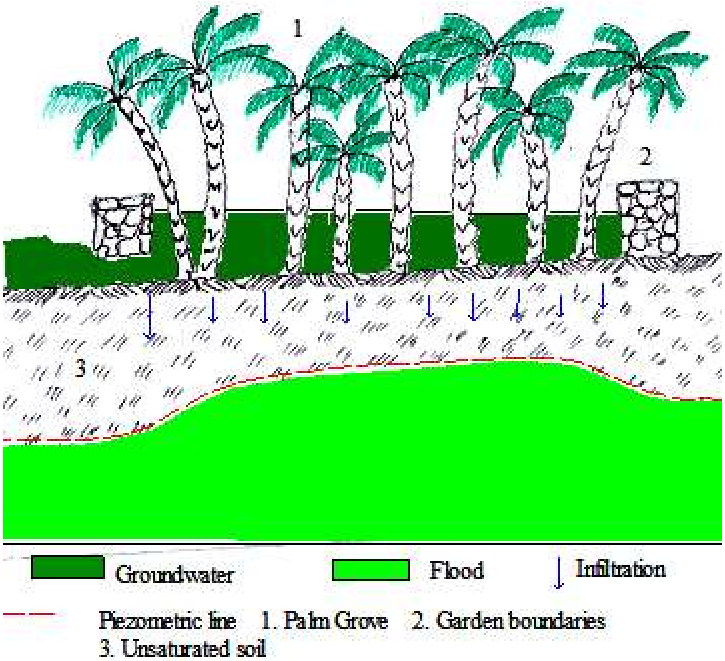


Figure 32: Approximate diagram of the garden recharge technique (Remini diagram, 2025)

Recharging alluvial aquifers through dam releases

Surface dams, which are affected by climate change, directly impact groundwater capacity through a double reduction due to siltation and evaporation. To minimize evaporation, dam releases must be carried out periodically to recharge the water table (Fig. 33).

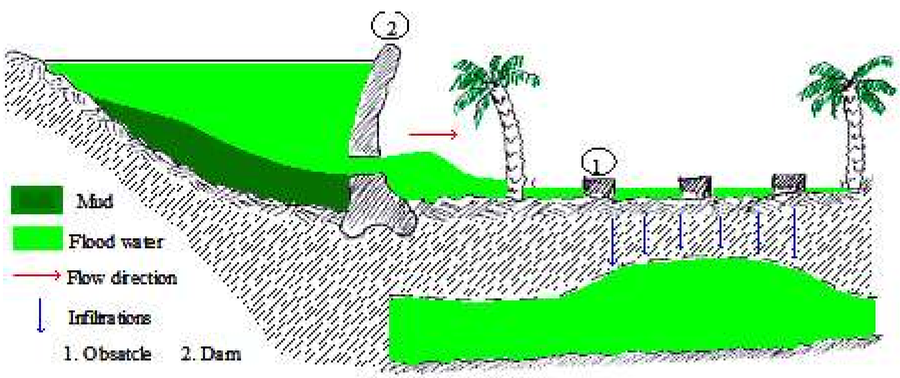


Figure 33: Obstacle technique (Baffle Shape) to accelerate groundwater recharge (Remini diagram, 2025)

An experiment conducted in a rectangular channel in the laboratory showed that a baffle-shaped arrangement of obstacles is the most effective for creating recirculating eddies. These eddies facilitate water infiltration into the subsoil (Fig. 34). Baffle-shaped obstacles should be installed just downstream of a dam to accelerate the recharge of the alluvial aquifer. It would be beneficial to generalize this obstacle technique to other dam sites. Even in sections of gently sloping wadis where the flow is fluvial, gabion barriers constructed in these sections of the wadis are a very effective solution.

Figure 34: The staggered shape of the obstacles in a wadi is the best arrangement for accelerating the recharge of the alluvial aquifer (Photo. Remini, 2004).

Recharging the alluvial aquifer through dam releases via bottom gate operations has become a very promising solution for minimizing evaporation from dam reservoirs and accelerating groundwater infiltration. Two experiments have been conducted in northern Algeria. The first was carried out on the Damous River upstream of the Kef Eddir dam (Fig. 35). The second experiment was conducted on the El Hachem River downstream of the Boukourdane dam.

Figure 35: Periodic water releases on the Damous River from the Kef Eddir dam (Photo. Remini, 2022)

The area downstream from the Kef Eddir dam is a prime agricultural region, thanks to continuous irrigation using water from the alluvial aquifer. All the wells in the surrounding gardens draw water from seepage originating in the inferoflux aquifer (Fig. 36). After each operation of the bottom gate, the water level in the wells rises rapidly.

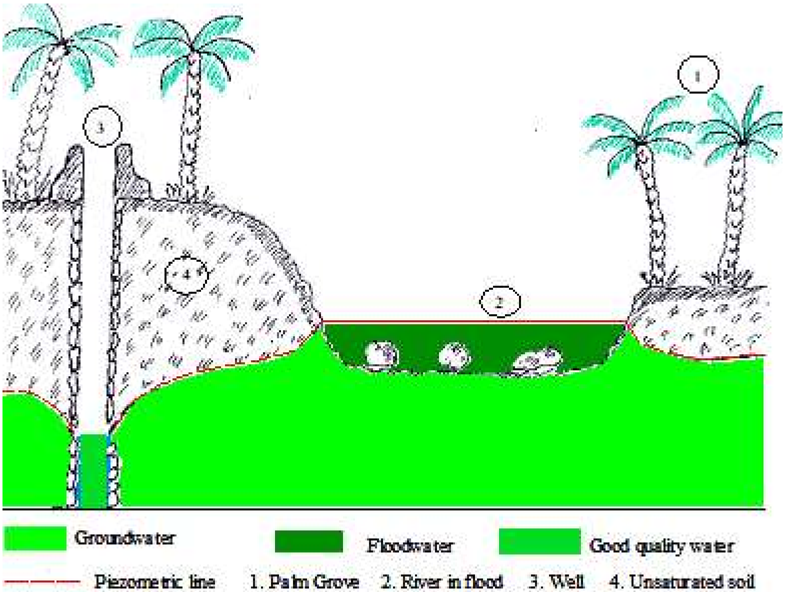


Figure 36: Damous River. Probable diagram of the well-wadi relationship (Remini diagram, 2025)

Recharge wells

Recharge wells are an Algerian invention originating in the oases of the Mzab and Mettlili valleys. This type of well has an opening at the bottom of the rim, at ground level. During periods of flooding, water flows directly into the well to replenish the water table. The wells are installed in gardens and in wadis (Figs. 37, 38, and 39).

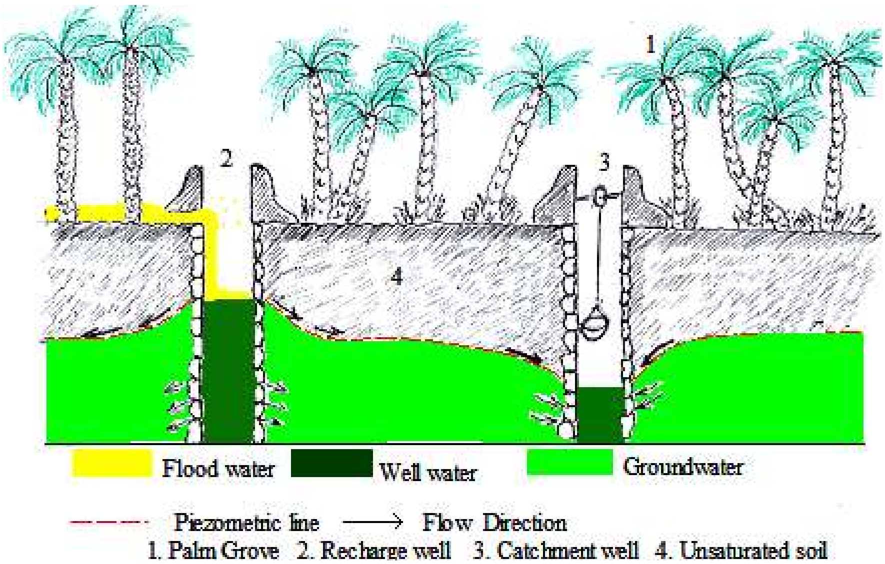


Figure 37: Probable diagram of two wells; Recharge and intake (Remini diagram, 2025)

Figure 38: **Recharge well in the Ghardaïa oasis equipped with an opening to allow floodwater to fill the well (Photo. Remini, 2012)**

Figure 39: **Recharge well in the El Guerrara oasis equipped with an opening to allow floodwater to fill the well (Photo. Remini, 2014)**

Flash Flood Recovery After Sand Dunes

In the Sahara, several wadis flow directly into the Ergs. This water can be recovered downstream of the dunes, which are naturally treated thanks to the infiltration of flash floodwaters over several kilometers through the sands (Fig. 40). The example of lEl Golea lake, downstream of the Grand Erg Occidental, illustrates this. This water is discharged upstream into the Erg Occidental by the Segguer and Zergoune wadis. After flowing for several kilometers under the sand, it reaches lake of Menea. Today, this lake is polluted by wastewater discharges from the city of Menea.

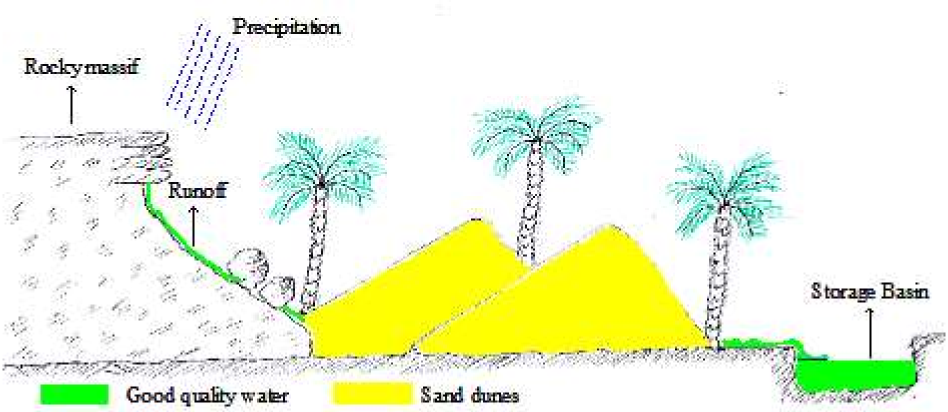


Figure 40: Simplified diagram of the role of sand dunes in purifying flash flood water (Remini Diagram, 2025)

Earthen Canals for Groundwater Recharge

Earthen canals with a rectangular or trapezoidal cross-section are a favorable option for infiltrating the canal water into the subsoil, thereby replenishing the groundwater (Fig. 41). This technique can be applied in the large palm groves of the Algerian Sahara, such as the Oued Righ, Tolga, Laghrous, and Foughala palm groves. However, existing transport canals are used to carry drainage water. Today, these canals are polluted by domestic wastewater discharge, and groundwater and canal water come into contact. The installation of wastewater treatment plants (lagooning) can solve a significant ecological problem and recover a considerable amount of fresh water. In this case, these canals will carry treated, high-quality water for irrigation. As an example, the Oued Righ canal will transport purified water from Goog to Chott Merouane over a distance of 120 km. In this case, the aquifer is replenished along this long route.

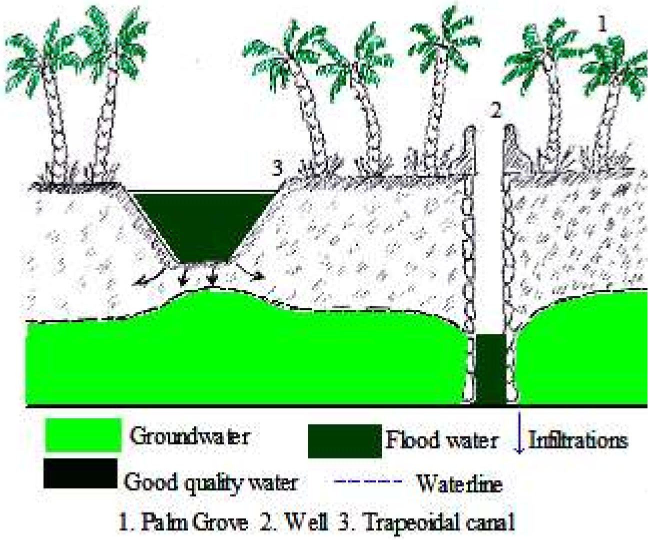


Figure 41: Simplified diagram of the infiltration channels for transported water used to recharge the water table (Remini diagram, 2025)

New watershed management plan for Algeria

Given the climate change currently affecting countries in the Mediterranean basin, and particularly Algeria, watersheds must adapt to this disrupted climate by adopting new rainwater harvesting techniques. The 150 wadis (seasonal watercourses) that flow through Algeria must be equipped with hydraulic structures capable of storing rainwater underground, protected from evaporation. Six hydro-agricultural structures can be built on the main wadis of a watershed. Depending on the hydrogeology and soil geology, the best site for one of the six hydraulic structures will be determined. Along a single wadi, we can construct all six hydraulic structures, and even repeat several along the wadi, culminating in a large surface dam at the outlet. This is a large-scale hydro-agricultural development that includes various types of groundwater recharge and water storage structures beneath the wadi beds and in the subsoil (Fig. 42). These hydraulic structures are as follows: (1) Underground dam or Inferoflux dam, (2) Sand dam, (3) Recharge dam, (4) Infiltration basin, (5) Covered dam (Djoub), and (6) Combination dam (surface dam above the underground dam)

Ideally, the wadi should be made much more profitable by maximizing the use of alluvial and groundwater. The increased number of sands, recharge, underground, combination, and covered dams, as well as recharge basins, along a wadi result in maximum artificial replenishment of the alluvial aquifers. With such a development, the relationship will be reversed; the rate of evaporated water will be much lower than the rate of infiltration.

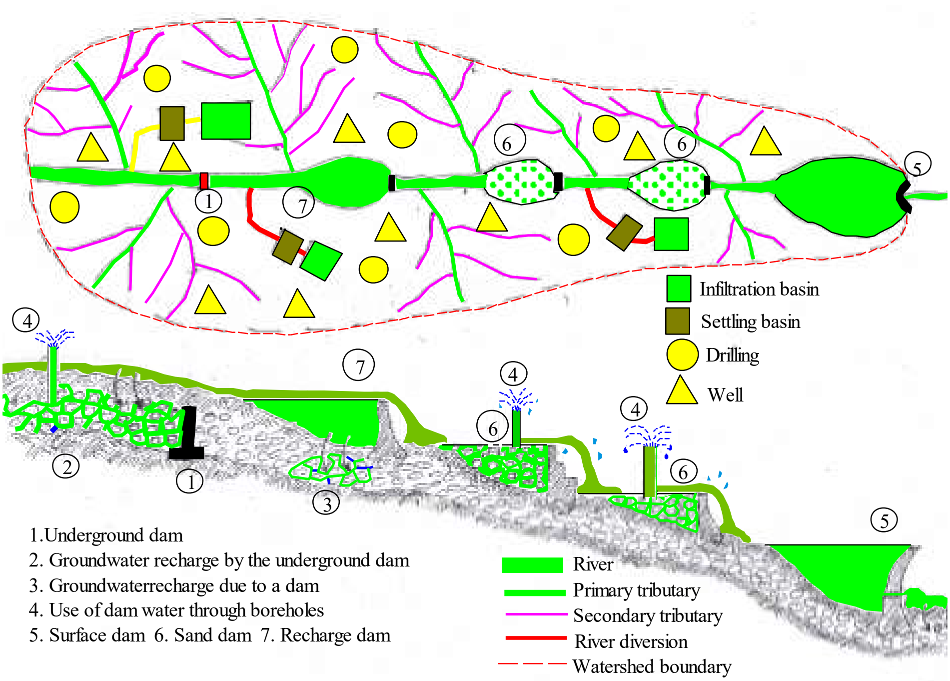


Figure 42: Approximate diagram of watershed management (Remini Diagram, 2025)

These new hydro-agricultural developments will be implemented throughout Algeria. The various hydraulic structures to be built across the entire hydrographic network, along with the hundreds of boreholes and wells to be installed in these watersheds, require high-level management of all these hydraulic structures. To this end, we propose a new division of Algeria into 8 hydrographic basins (Fig. 43).

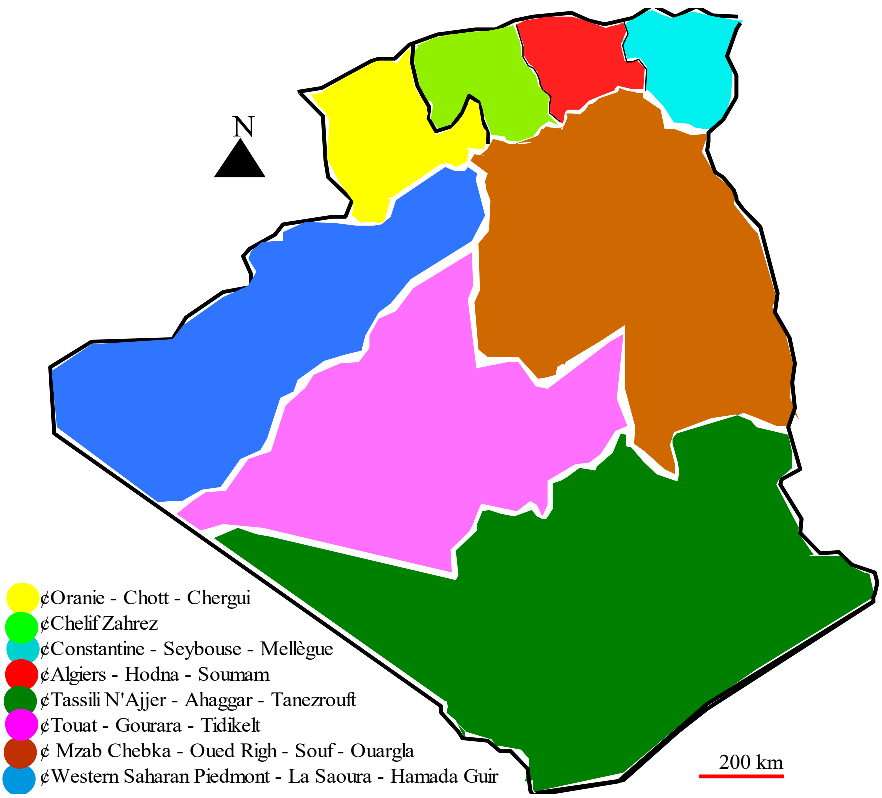


Figure 43: Diagram of the new division of Algerian river basins (Remini Diagram, 2025b; Remini, 2025c)

In Search of new aquifers

The search for new water reserves in Algeria's subsoil has never been discussed, yet exploration of the Algerian subsoil in search of hydrocarbons continues unabated. How is it that in a country as vast as Algeria, with an area of 2.38 million km², no prospecting campaign for new aquifers has been conducted since 1962? Given the climate that favors droughts, prospecting for natural reservoirs is essential. What prompted us to choose this path is that today, discoveries of new water deposits are multiplying across the globe. Indeed, in 2013, an exploration of groundwater resources identified significant reserves in Turkana, located in northern Kenya: a gigantic aquifer of 200 billion m² of fossil water, extending over a hundred kilometers (Paupier, 2013).

In Namibia, a major discovery of an aquifer estimated at 5 billion cubic meters was reported in 2012 (Mauguit, 2012). In France, a deposit of "blue gold" was discovered in the Oregon Volcanoes. A giant aquifer estimated at 81 billion cubic meters of water (Karlstroma et al, 2025). This water reservoir is located more than 100 meters deep. The water circulates through fissures in volcanic rock. Its recharge depends primarily on snowmelt. There is a strong resemblance to the cases of the Djurdjura Mountains and the Chréa Mountains.

Regarding water, Algeria warrants in-depth studies and exploration of new water reserves throughout the country. There are enormous potential water reserves hidden underground, particularly in the Algerian Sahara, which has yet to uncover these secrets. Regarding water resources, let's look back at our history of water. For 20 centuries, the oasis dwellers of Touat and Gourara were the first to exploit the waters of the Continental Intercalaire using foggaras (underground irrigation systems) (Remini, 2017a). For over 10 centuries, farmers in the oases of Tindouf, Sfissifa, and Tamanrasset have been using foggaras to draw water from the subsurface aquifer of the Tindouf and Tamanrasset wadis (Remini, 2020). Farmers in the Timimoun oasis use foggaras to draw water from the Grand Erg Occidental aquifer (Remini, 2024b). Today, we don't know the number or quantity of these alluvial aquifers and the aquifers of the Ergs. Even in the Sahara, groundwater has never been identified or assessed. Therefore, alluvial aquifers, whether in the south or the north, have never been the subject of in-depth study. Regarding transboundary aquifer systems, Algeria is affected by six aquifer systems, three of which are considered major water basins. These are the Northern Sahara Aquifer System, the Iullemeden-Taoudéni-Tanezrouft Aquifer System, and the Mourzouk Aquifer System. The Northern Sahara Aquifer System is the only reservoir that has been relatively assessed and studied, but it needs to be reviewed and re-examined. Capacity and groundwater drawdown are two parameters that need to be reassessed. However, the study should focus on the exploitation of the Iullemeden-Taoudéni-Tanezrouft Aquifer System, which covers an area of 2.5 million km^2 and is traversed from end to end by the Niger River. Part of this aquifer lies beneath the Tanezrouft Desert in the Algerian Sahara. What an opportunity for this extremely arid region (Tanezrouft) to become a prime agricultural area! It should be noted that this mega-reservoir is shared between seven countries: Algeria, Benin, Burkina Faso, Mali, Mauritania, Niger, and Nigeria. Furthermore, there is the possibility of replenishing this aquifer via the Niger River. Renewable water beneath Tanezrouft is a subject that needs to be studied. It is worth emphasizing that more than 50% of Algerian territory lies above sea level. It is time for the water management services to properly assess our country's freshwater reserves.

CONCLUSION

As mentioned at the beginning of this paper, ensuring a country's water security is becoming more complex than simply addressing climate change. Currently, Algeria's freshwater reserves are around 13 billion m^3/y. This is a deficit of approximately 7 billion m^3/y to achieve truly satisfactory water security. Prolonged periods of drought have encouraged the water in reservoirs to evaporate and return to the surface. However, the dead water volume in most reservoirs can be utilized, while others have dried up. Such a situation, a consequence of climate change, could recur in the coming years. In addition, a total of 2 billion cubic meters of silt lies at the bottom of 83 dams in operation, with a combined capacity of 8.5 billion m^3. For the past twenty years, Algeria has turned to seawater, an inexhaustible but salty resource. Money and energy are required to remove these tons of salt. Eighteen desalination plants have been installed along the Algerian coast to produce 1.35 billion m^3/y of drinking water. The coming years will be more challenging, given the rapidly growing population and Algeria's fast-developing sectors, including drinking water supply, energy, mining, agriculture, and industry. To meet these needs, a freshwater reserve of 80 billion m^3/y will be required by 2060. An additional 2 m^3/y will be needed each year to satisfy all water demands within the next 35 years. Algeria must utilize its four water sources (rainwater, seawater, fossil water, and wastewater). Algeria must continue its seawater desalination program, but brine discharges must be controlled. Regarding fossil water, Algeria must study and define the areas for water exploitation in the Mourzouk Basin and the Taoudéni/Tanezrouft/Iulleden aquifer system. As for rainwater, Algeria currently only utilizes 7% of the annual rainfall in northern Algeria, estimated at 100 billion m^3. Therefore, a portion of the 85 billion cubic meters that evaporate each year must be recovered. Two options exist for recovering this evaporated water. The first is to directly capture the water vapor using a hydraulic system. The second option is to store rainwater underground, protected from evaporation, using various hydraulic structures originating from the Sahara. These include underground dams, sand dams, recharge dams, and groundwater recharge basins.

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Declaration of competing interest

The authors declare that there are no known financial or personal conflicts of interest that could have influenced the research presented in this paper.

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