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FLASH FLOODS IN ALGERIA

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ABSTRACT

Flash floods in Algeria, this paper discusses the characteristics of these new floods. In reality, these floods are of Saharan origin and are caused by torrential rainfall, the equivalent of 3 to 12 months falling between 24 hours and 72 hours. In recent years, these floods have moved toward northern Algeria and even in certain countries of the Mediterranean basin. In addition to the brutality and aggressiveness, these flash floods are characterized by the significant quantities of fine particles transported, which reflect the resizing of the hydrographic network and the digging of new gullies in the watershed to evacuate the large masses of water transported. by these floods. Rainwater evacuation systems (sanitation networks and flood spillways) are currently undersized in the face of these new floods. Flash floods are a little-known subject that requires in-depth studies to predict them.

Keywords: Flash flood, Mud, River, Sahara, Climate change.

INTRODUCTION

Time flies, the climate changes quickly! Everyone realizes that climate change is indeed accelerating. Temperature and precipitation are two essential parameters that have changed in recent years and consequently changed the climate. Diametrically opposed, one (temperature) increases and the other (precipitation) decreases, and the result is the outcome of two extremes: a long period of drought followed by heavy flooding. Is there a reconversion of the Mediterranean climate toward a desert climate? A long period of drought characterized by record temperatures exceeding 40°C was recorded in certain cities in Algeria and even countries in the Mediterranean basin. Flash floods and devastating floods occur just after the hot season. A large amount of water and dust drained by floods, but the rivers do not have the capacity to evacuate an exceptional quantity of loaded water. It is possible that the flow of the flood was not even archived.

Such a quantity of water represents the equivalent of the volume of water expected to fall in 3 to 12 months, falling today between 24 hours and 72 hours. Algeria and even countries in the Mediterranean basin have recorded gigantic, devastating and deadly floods. However, these floods are characterized by a rapid rise in water level over a short period of time. In this case, we are discussing flash floods, which are a main characteristic of the Sahara. Therefore, the notion of slow floods will gradually disappear, giving way to flash floods.

In Algeria, no serious study has been carried out on these new floods, despite the damage recorded during recent years in the northern part of Algeria. The favorable period for the appearance of these floods was the months of September, October and November, but at the time, no one differentiated between flash flooding and slow flooding. Moreover, the arrival of the autumn season scares the population since it has become a season of floods and floods. However, for the dam builders, it was the time for filling the dams, but it was also the right time for the dams to silt up, since these floods drain significant quantities of mud (Remini, 2022). Today, a new climate is taking hold in the Mediterranean basin. It is characterized by a long duration of drought followed by a short duration of floods and floods (Remini, 2023).

Climate change has reached the countries of northern Africa and the southern Mediterranean basin. Italy has not escaped this process of tropicalization (Le Parisien-Environnement, 2023). Today, the subject of “flash flooding” is relevant, but it is still in its embryonic stage. However, our presence over the last 30 years in the Sahara for water research work has given us the chance to see the damage caused by these flash floods. Several floods took place, notably during the month of October 2008, when all the Mzab and Saoura valleys experienced water revolt. On the basis of all this information and the data that we have measured collected and retrieved from competent services, this article has been formatted. This is just the beginning on a subject as fascinating as flash floods.

LIGHTNING FLOODS-RELATIONSHIP WITH THE NEW CLIMATE

Time passes quickly, the climate changes quickly, and we are heading toward a new climate that is settling in the Mediterranean basin. It is characterized by a long-term drought marked by record temperatures and intense evaporation and is sometimes accompanied by forest fires. Its duration increases from 4 to 7 months, and this drought will be followed by a short wet period marked by violent rains that cause torrential floods and consequently deadly floods (Fig. 1).

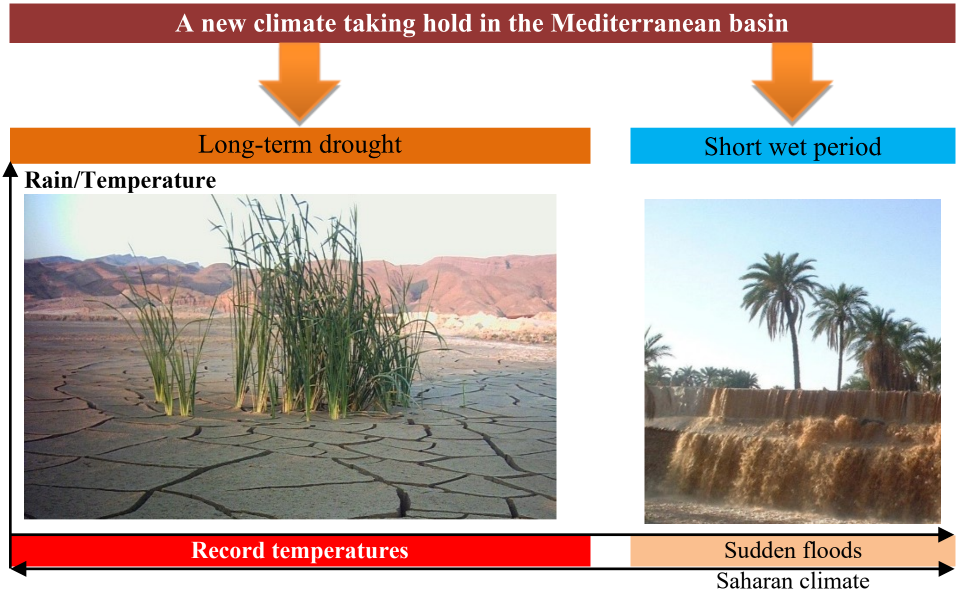


Figure 1: Saharan climate (Remini, 2023)

The two essential characteristics of the new climate are the long dry season marked by record temperatures exceeding 40°C and the short season marked by torrential rains producing flash floods. In this study, we emphasize flash floods, which are sudden floods but differ from slow floods (Fig. 2). The latter correspond to a rise in the level of a watercourse, but which takes place over several days or even several weeks. This flood occurs in medium and large basins. Slow flooding occurs during the winter season. Long-lasting and continuous precipitation initially causes water saturation of the soil. The water is no longer able to infiltrate into the basement, and as a result, the water flows and spreads in large quantities and can last for several days or even weeks. These lasting floods generate formidable floods that are only as serious as those produced by flash floods. Only flooding caused by slow floods can also cause human and material damage.

A flash or sudden flood is a flood that forms within a few hours. Torrential rainfall equivalent to 3 to 12 months falls between 24 hours and 72 hours. This causes a sudden rise in the level of the watercourse, causing catastrophic and deadly floods. Generally, these floods are caused by violent and localized rains, which are generated by thunderstorms, storms and even cyclones. The rapid rise in water caused by the sudden effect of the flash flood causes a sudden overflow of the hydrographic network and consequently will produce deadly floods.

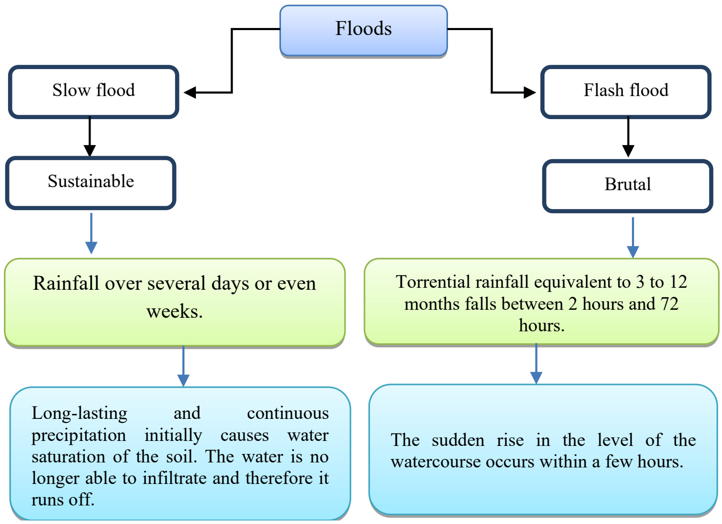


Figure 2: Difference between the two floods: slow and flash (Remini, 2023)

The flash flood is none other than the flood that occurs in the Sahara Desert. We prefer to call it the Saharan flood. This flood rose toward northern Africa and then toward countries in the Mediterranean basin, such as Italy, Spain, France and others. The Saharan flood is characterized as follows:

- Like a muddy flood with a very high concentration of fine particles and carrying an impressive liquid flow.
- Like an aggressive flood, it is driven by an exceptional tractive force that can carry away all the existing obstacles in its route.
- Like a flood, which carries floating objects such as animal corpses and tree trunks that can cause the “wave” phenomenon or the water hammer of the Saharan flood.

FLASH FLOODS-SIGNIFICANT LIQUID AND SOLID DELIVERY

Flash floods, even if they occur within a few hours, drain significant quantities of water and solid particles. The rise of water in rivers occurs quickly so that all evacuation systems are unable to evacuate the water. In recent years, the floods that have occurred in Algerian territory have been flash floods. For this study, we chose four Saharan floods that have occurred over the last 20 years in Algeria and Libya. During the exceptional flood of 2001, which occurred in the Bâb El Oued district of Algiers, we noticed impressive quantities of mud drained by the flood. In fact, the flood occurred on November 9 and 10, 2001, after a long period of drought (Fig. 3). Exceptional rains of approximately 260 mm fell during 38 hours (from 9:30 a.m. on 9/11/2001 until 1:00

p.m. on 10/11/2001) were sufficient to trigger a sudden flood estimated at 730 m^3/s (Fig. 4). This caused the water to rise rapidly. It is typically a Saharan flood that today is called a flash flood.

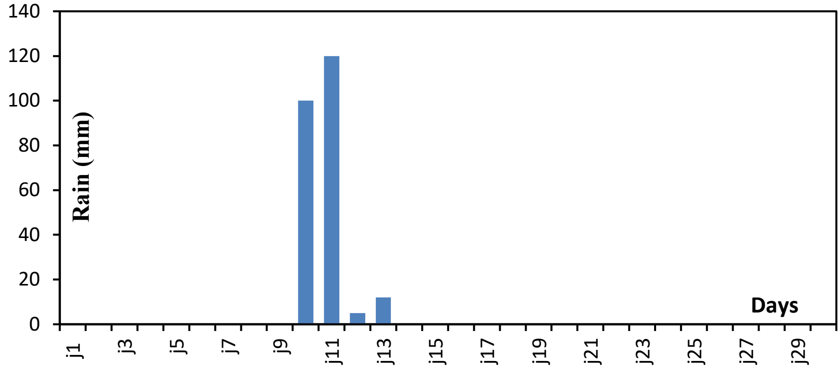


Figure 3: Rainfall of November 9 and 10, 2001 (National Water Resources Agency data)

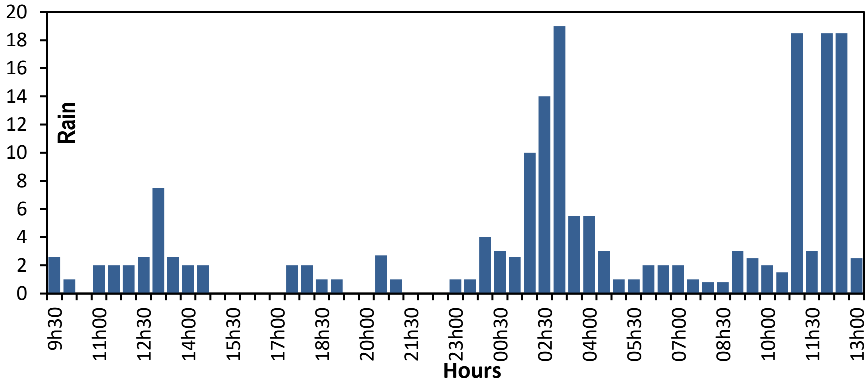


Figure 4: Histogram of the downpours in Algiers from 09/11 to 10/11/2001 (Bir Mourad Rais station - National Water Resources Agency data)

The rapid rise in water levels caused deadly floods. More than 1,000 people died during the two days of flooding. However, we were impressed by the mass of mud carried by the flood, which was estimated at approximately 800,000 m^3 (Boutoutaou, 2007). This volume was determined based on the number of trucks that evacuated these earth embankments outside the capital. Certainly, this is an estimate but it does not interpret reality, since a fairly large quantity of mud was dumped by the flood into the sea. The volume of mud drained by the flood far exceeds 0.8 million m^3 and is approximately 1.5 million m^3 (Fig. 5(a and b)). It was for the first time in Algeria to see a fairly large quantity of mud carried by the flood. These tons of mud are the result of a process of erosion of new gullies and Chabat. The hydrographic network was subjected to intense erosion to resize the sections.

a) Alleys submerged by earth

b) More than 5 meters in height of the mud deposit

Figure 5: Mud everywhere in the Bâb El Oued district during two days of rainfall (Photo. National Water Resources Agency, 2001).

The second Saharan flood took place in Mzab Wadi on October 1, 2008. This flood was generated by rains of exceptional intensity. The rain gauge recorded 43 mm in 24 hours. However, the parameter that gave power to this flood was the flow in the two tributaries (Laadira, Labiod), which took place at the same time for the first time. This caused a rise in the water level of more than 2 meters in certain sections with a width exceeding 400 meters. A torrential flow of rare power occurred in the Mzab River with a length of 4 km from Amlaga (meeting point of the Laadira River and Labiod River) to the Ahbas N'Bouchen dam located at the limit of the palm grove of the Ghardaïa oasis. This generated an exceptional flow that reached Sebkha Sefioune, the drop-off point of Wadi of Mzab. Despite the obstacles of dams and palm groves, the flow finished to reach its total route of 300 km. The flow rate that we attributed to this flood was 1200 m^3/s. What impressed us at the time was especially the quantity of mud drained by the flood, which we estimated at 600,000 m^3/s. This high figure clearly explains that upstream, there was erosion work at the watershed level and undermining of the banks. This falls well within the framework of digging new ravines and widening the section of wadis. Unfortunately, these flash floods generate flooding, causing material damage and human losses. We recorded the deaths of 43 people and several homes destroyed, particularly those built on the major river of the Mzab River (Fig. 6).

Figure 6: Damage caused by the passage of the flood on October 1, 2008, in the Wadi of Mzab (Photo. Remini, 2008)

The third flash flood took place in 2011. It was during the period from October 28 to 31, 2011 (i.e., a duration of 80 hours), a flood of rare violence whose peak flow was estimated at more than 1600 m^3/s occurred on the Wadi of Labiod. Starting from the heights of Chelia in the Aurès, the Labiod River with a length of more than 100 km leads to the Foum El Gherza dam with a capacity of 47 million m^3. For the fault type, the Foum El Gherza dam resisted this famous flood well despite the discharge by the flood spillway and the evacuation by the bottom valve, and the level continued to rise. The Foum El Gherza dam received an inflow of 205 million m^3 of water during the year 2011/2012 (Fig. 7). This contribution is classified as the largest since its impoundment in 1950. This is due to the flood of November 2011, which drained a peak flow equal to 1600 m^3/s.

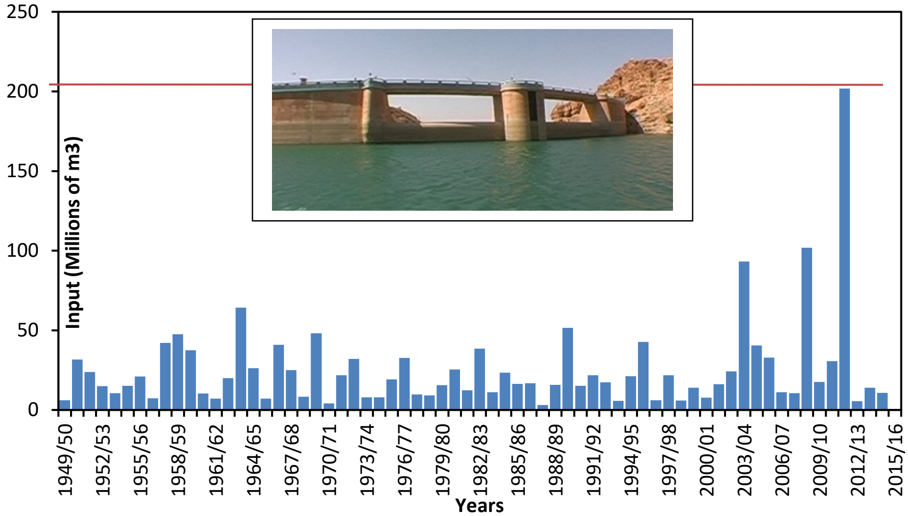


Figure 7: Contributions to the dam since its impoundment (National Agency for Dams and Transfers data, Photo. Remini, 1994)

With a length of 120 km, the Labiod wadi is different from other wadis since it is made up of different sections ranging from 450 m wide around Lahbel (Biskra) to 20 m wide around Mchouneche (Biskra) (Fig. 8).

Figure 8: Labiod River, 120 km long and 450 m wide, around Lahbel (just before the dam lake) (Photo. Remini, 2014)

It is also composed of different slopes ranging from 1/1000 to 6/1000. This generates Venturi, which gives the flow energy to reach the dam with appreciable liquid contributions. However, this type of flow erodes the banks and the watershed. These quantities of fine particles torn from their initial positions continue on their way to reach the dam lake. Only the 2011 flood is described as an exceptional flood from the point of view of liquid water supply and solid supply. According to our estimates, the silt deposited at the bottom of the reservoir exceeded 1 million m^3. For comparison, the Foum El Gherza dam receives an annual volume of 0.7 million m^3/year. During its history, for more than 70 years of operation, the dam has never received a liquid input of 205 million m^3 during a single flood (with a flow rate of 1600 m^3/s) and a solid input of more than 1 million m^3. This does not mean that this value of 1600 m^3/s is a flow rate that has never been conveyed by Wadi of Labiod. It is possible that such a flood appeared on Wadi of Labiod well before the archives even appeared.

THE FLASH FLOOD; AN AGGRESSIVE FLOOD

One of the characteristics of the Saharan flood (or flash flood) is aggressiveness and brutality. It is driven by a formidable tractive force capable of pulling with it all the natural or artificial obstacles existing in its path. Some floods that occurred during the last 20 years were taken as examples.

Oued M'Zi - Flood of September 30, 2016

With a length of 420 km, the M'Zi wadi originates in the Saharan Atlas and, more precisely, in the Aflou region and flows into Chott Melghir. Arriving at Messad, the M'Zi wadi takes the name of the Djedi wadi. With a very variable section ranging from 200 m to more than 1000 m in width. The M'Zi wadi goes from a height of 1250 m at Aflou to -20 m when it arrives at Chott Melghir. The wadi of M'Zi is very well known for these Saharan floods, which are increasingly appearing. The highest flood that occurred on the M'Zi wadi was 2400 m^3/s. The last flood that occurred dates back to September 30, 2016, with a traction force of approximately 100 N/m^2, which caused an accident at the level of the pipeline that crossed the M'Zi River if the cant height of water exceeded 2 m at certain sections; unfortunately, the flow rate was not estimated. It has been reported that several tons of mud are transported by floods.

Figure 9: M'Zi River– Flood of September 30, 2016. Shearing of the pipe (Photo. Sonatrach, 2016)

Ittel River - Flood of September 3, 2020

Another interesting example is the flood that occurred on the Ittel River on September 3, 2020. A brutal and sudden flood occurred in the locality of El Baadj on Thursday September 3, 2020, and the pipeline transporting oil to Terminal Arrival from Skikda was brutally sheared at the place where it crossed the Ittel River and led to the spilling of a significant quantity of oil (Fig. 10).

Figure 10: Ittel River- Saharan Flood of September 3, 2020. Brutal shearing of the pipe. (Photo. Sonatrach, 2019)

Labiod River- Flood from October 28 to 31, 2011

The largest flood occurred on the Labiod River for 80 hours (October 28 to 31, 2011) with a flow rate of 1600 m^3/s. Before reaching the Foum El Gherza dam and after exiting the Labiod River cannon from a very tight section whose width does not exceed 30 m. The speed of the flow was so great that the bridge crossing the Labiod River (to reach the village of Mchouneche) located 5 km from the outlet of the cannon was swept away in its path (Fig. 11).

Figure 11: A bridge crossing the Labiod wadi to reach the village of Mchouneche was swept away by the flash flood that occurred from October 28 to 31, 2011 (Photo. Remini, 2011)

Tiout River, May 30, 2020

For more than 7 centuries, the ancestral Tiout dam has resisted the various floods that have occurred on the Tiout wadi (Fig. 12). Unfortunately, the flash flood that occurred on May 30, 2020, was so brutal that the dam was not able to withstand the exceptional force of the flow that destroyed the dam.

Figure 12: Tiout River – Flood of May 30, 2020. The ancestral dam is no longer. The hydrotechnical heritage was washed away by the Saharan flood (Photo. Remini, 2009).

Figure 13: The banks of the wadi were eroded by flash floods that crossed the Asla oasis (Photo Remini, 2012)

Floods of October 2008 in the Saoura oases

The month of October 2008 was a climatological event but was not popularized. All the oases of the Mzab valley, the Saoura and the Ksour Mountains have suffered historical floods (Fig. 13). Going from the oases of Ghardaïa, Ain Sefra, Tiout, Asla, Chellala, Boussemghoun, Sfissifa, Tiout, Moghrar, Chellala-Dahrania, Chellala-Gueblia, Arba-Fougani and Arba-Tahtani and Bechar. Sudden floods occurred in the wadis that cross these oases. The rapid rise in water levels in these wadis caused flooding, which caused significant material damage.

FLASH FLOODS DRAIN FLOATING BODIES

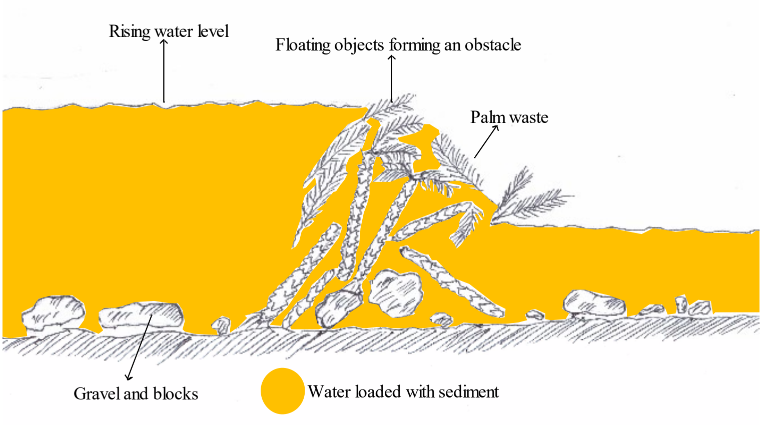
The hammer blow of the Flash flood

The passage of these Saharan floods on the major beds of these wadis uproots and takes palm trees with them. These palm tree trunks are transported in suspension by Saharan floods. Along these wadis, there are natural obstacles (narrowing of the wadi) and artificial (bridge piers) that block these floating bodies by creating temporary dams (Figs. 14, 15 and 16a).

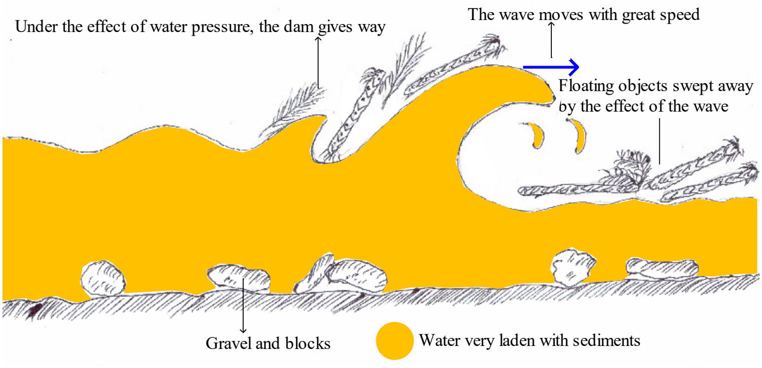
Figure 14: Floating objects formed a temporary barrier on the bridge in downtown Ghardaïa (Photo. Heritage)

Figure 15: The bridge piers on Wadi of Saoura favored the formation of a temporary dam made of brush and palm tree trunks. The latter gave way to the pressure generated by the rapid rise of the water. This is the hammer blow of the Saharan flood. (Photo. Rezoug, 2014).

Under the effect of the water pressure (induced by the rise of the water) on the dam created by the palm tree trunks, the latter gives way and creates a wave that causes a wave that moves with great speed called the wave phenomenon (Fig. 16b). For us, we nicknamed this phenomenon the Ram blow of the Saharan flood.



a) Formation of an obstacle by floating object



b) Appearance of a rapidly moving wave

Figure 16: The phenomenon of ram blows; a characteristic of the Saharan flood (Diagram Remini, 2023)

Floating bodies at the level of dam lakes

As we mentioned at the beginning of the article, this type of flood (the Saharan flood) transports in addition to mud, all floating objects and, more particularly, animal corpses and tree trunks. During the last 20 years, we have carried out research missions in the oases of the Algerian Sahara; we have often observed that these Saharan floods transport mainly the trunks of palm trees since these floods cross the palm groves of the oases, which are located on the major beds of the rivers (Fig. 17).

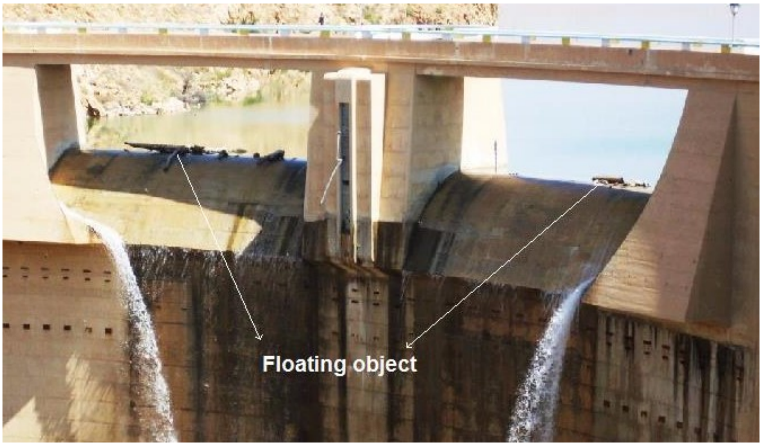
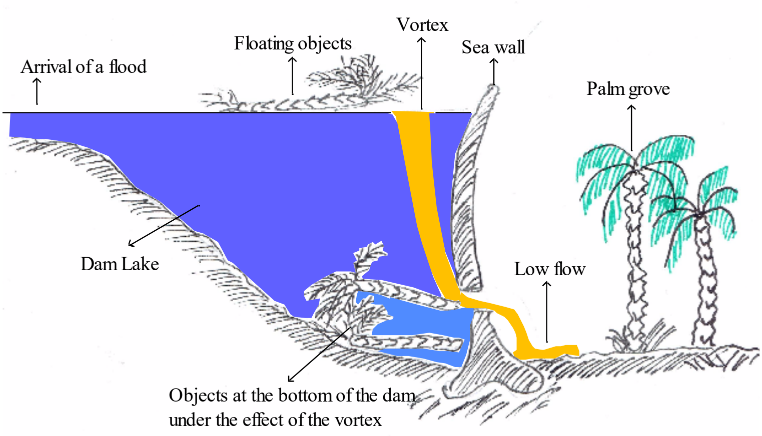


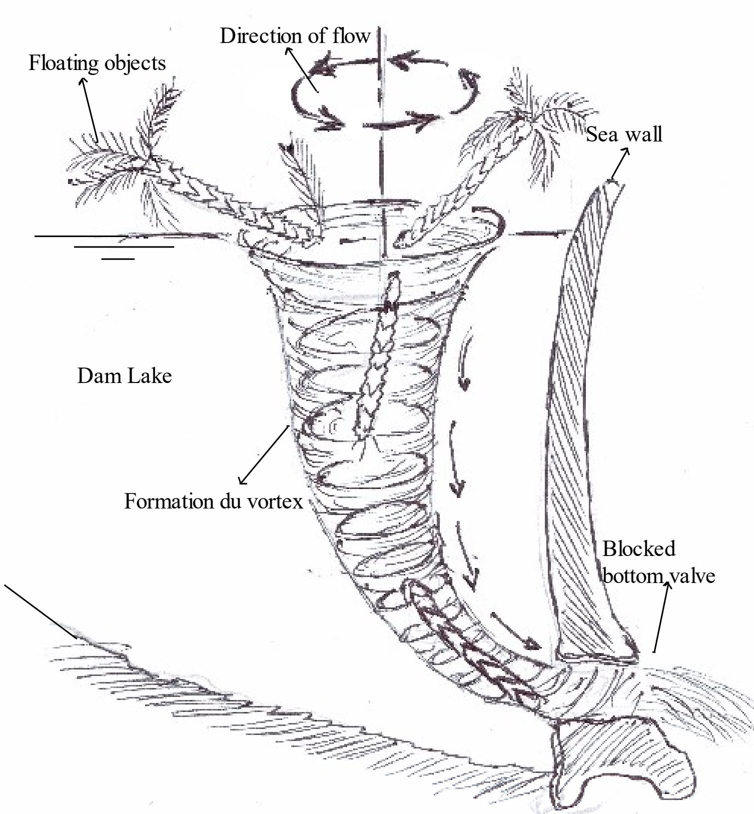
Figure 17: Foum El Gherza Dam - The flood-transported floating objects such as palm tree trunks (Photo. Remini, 2008)

Blockage of the bottom valve

The entry of a flash flood into contact with the waters of a dam causes the formation of a density current that propagates on the bottom of the reservoir in the form of a sheet of muddy water without mixing with the clear waters of the dam. Opening the bottom valve to draw off the density current before it consolidates can pose problems in managing the drainage channels. Indeed, when a flash flood arrives, floating objects, particularly palm tree trunks, are carried away by the flood. The opening of the bottom valve creates the vortex phenomenon, and consequently, the palm trunks are carried away by the effect of the vortex created by the vortex (Fig. 18a and b). Then, these palm trunks are sucked toward the bottom and evacuated toward the outlet through the opening of the bottom valve. However, generally, this is not the case we observe. Sometimes tree trunks become stuck at the bottom, and therefore, maneuvering the drain openings becomes complicated.



a) Formation of a vortex



b) Enlarged diagram of a vortex

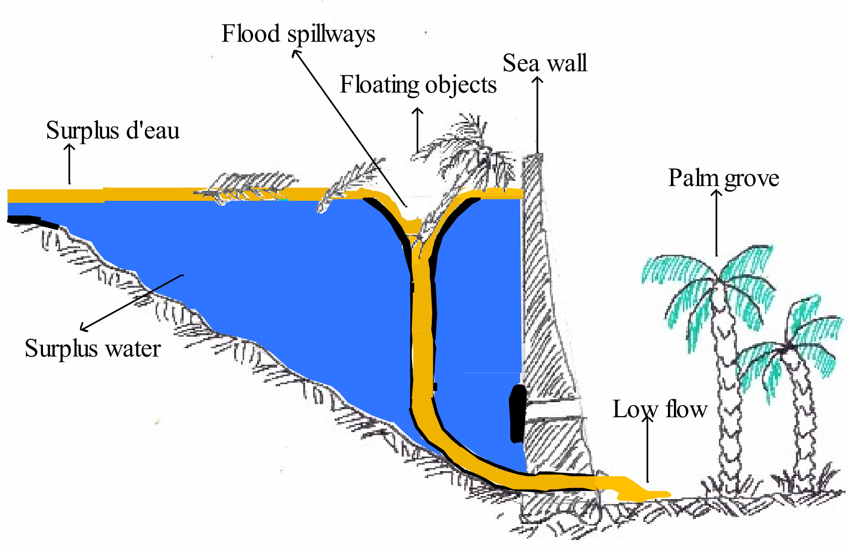
Figure 18: Simplified diagram of the vortex generated by the opening of the bottom valve of a dam (Diagram Remini, 2023)

This is the case at the Foum El Gherza dam (Biskra), where I myself attended this operation to unblock the drainage channels during the year 2006. In fact, the dam manager opened the valve bottom after the arrival of a flood to draw off the density current. Unfortunately, palm tree trunks were sucked in by the vortex generated by the opening of the bottom valve. This complex situation made closing the bottom valve an impossible operation; a palm tree trunk obstructed the closing of the bottom valve. The valve remained semiopen for a week, and as a result, several cubic meters of water from the dam were released (Fig. 19).

Figure 19: Under the effect of the vortex, caused by the opening of the valve for withdrawing the density current, a palm tree obstructed the closing of the bottom valve of the Foum El Gherza dam (Biskra) in 2006 (Photo. Remini, 2006).

The flash flood and its spillway

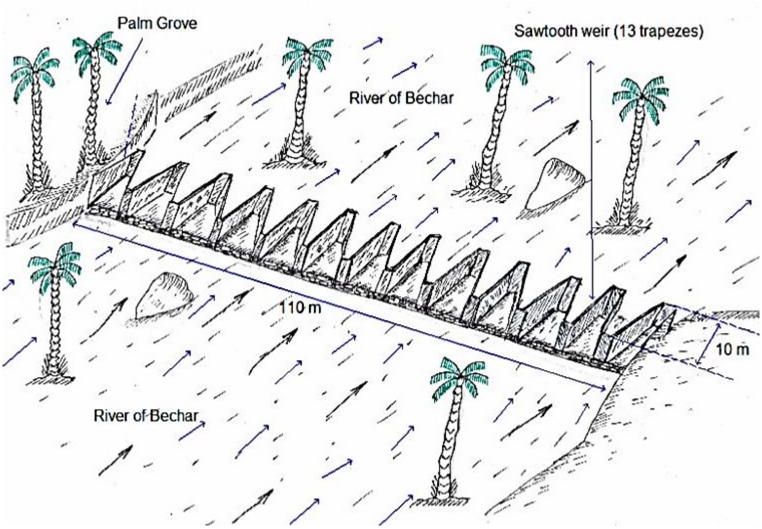
Known for its aggressiveness and brutality, the flash flood drains floating objects with it and abandons them in the dam lake. The creation of a flow will cause the movement of these floating bodies. At the dam, the drainage channels and the spillway can create a flow. Opening the bottom valve creates a vortex that causes a downward swirling movement of the fluid, taking with it the floating bodies and, more particularly, the palm tree trunks. The Tulip type spillway does not correspond to dams located in arid regions. Floating objects drained by a flash flood can become stuck in the penstock of the Tulip-type flood spillway (Fig. 20a and b). This will inevitably lead to the blockage of the spillway, and consequently, the water body of the lake risks reaching and exceeding the crest of the dam. Care should be taken to avoid building Tulip-type spillways for new dams in regions that experience flash floods. Other types of spillways can cause floating objects to become blocked (Fig. 21a and b).



a) Probable diagram of a tulip-shaped spillway (Diagram Remini, 2023)


b) Tulip-type flood spillway (Photo. Remini, 2006)

Figure 20: Funnel-shaped spillway



a) Diagram of the first weir dam constructed at the end of the nineties (Remini and Rezoug, 2018)

b) New weir barrage constructed at the end of the Ninety (Remini and Rezoug, 2018)

Figure 21: Flood spillway of the small Bechar dam (Remini and Rezoug, 2018)

Flash floods pollute raw water from desalination plants

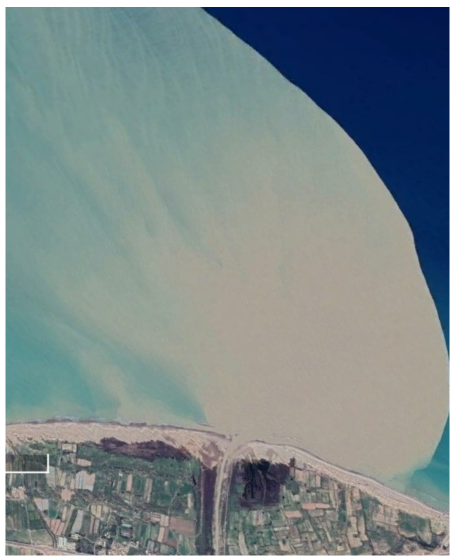
In the hydrographic network of northern Algeria, we identified 50 active wadis with a length of 1500 km that empty into the Mediterranean Sea (Table 1). Each year, Saharan floods discharge a quantity of 120 million tonnes into the Mediterranean Sea (Demmak, 1982). If these considerable Saharan floods discharged into the sea are beneficial for aquatic life, these flash floods pollute the raw water of seawater desalination stations. In Algeria, 12 seawater desalination stations produce 2.2 million m^3/day of drinking water. This value remains theoretical and difficult to achieve since the efficiency of a desalination plant does not depend only on the desalination process but above all depends on the correct choice of the water intake location. Saharan floods discharge considerable quantities of fine particles into the coastline (Fig. 22a, b, c and d). In this case, raw water becomes too loaded and difficult to use by desalination processes. This polluted raw water must be passed through a longer pretreatment stage. Even the lifespan of the membranes decreases over time, and consequently, the cost price of a m^3 of water becomes even more expensive.

Table 1: The wadis flowing into northern Algeria (Remini and Amitouche 2023a; Remini and Amitouche 2023b)

N	Name of River	Lenght (km)	N	Name of River	Lenght (km)
1	Tleta	12	27	El Harrach	15
2	Tafna	110	28	Hamiz	50
3	Meknassia	27	29	Corso	10
4	Halloufa	25	30	Merdja	5
5	Essenan	37	31	Isser	80
6	Guessiba	12	32	Larba	4
7	Tassmanit	4	33	Sebaou	80
8	El Kerma	6	34	Mleta	24
9	El Hammam	30	35	Youssef	27
10	Chellif	275	36	Ntaida	22
11	Guelta	12	37	Daas	21
12	Tarzoot	15	38	Saket	12
13	Allala	20	39	Soummam	60
14	Boucheghal	8	40	Agrioun	23
15	Goussine	412	41	El Kebir	42
16	Mentrach	12	42	Zhour	15
17	Ouattar	5	45	Tamanarat	9
18	Damous	36	44	Guebli	36
19	Kellal	6	45	Zeramna	15
20	Essebt	12	46	Kebir	36
21	Messelmoun	15	47	Seybouse	35
22	Hachem	22	48	Khelidj	15
23	Nador	8	49	Bounamoussa	20
24	Merzoug	4	50	MessidaZiama	10
25	Mazafran	17	51	Ziama	6
26	Beni Messous	10			

a) Flood on the Sebaou River

b) Flood on the Chéliff River



c) Flood on the Tafna River

d) Flood on the Chellif River

Figure 22: Flash floods dump impressive quantities of sediment into the Mediterranean Sea (Google Earth) (Remini an Amitouche 2023a; Remini and Amitouche 2023b)

FLASH FLOODS RE-SIZE THE WADIS

The wadis of the Sahara have very wide sections even exceeding 1 km, similar to the wadi of Tamanrasset and Djanet. This is explained by the fact that over the centuries, the wadi section has become accustomed to flash floods, and consequently, the immense flow of drained water brought by these floods erodes and sculpts the sections to evacuate these masses of water (Fig. 23). We are talking about resizing hydrographic networks.

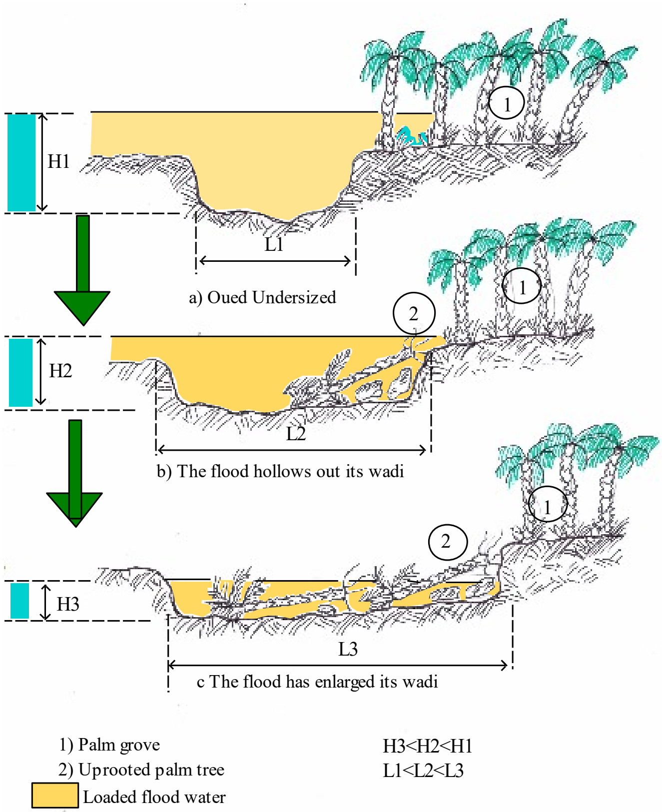


Figure 23: Probable diagram of the process of enlarging sections of the wadis (Diagram Remini, 2023)

With this new climate settling in the Mediterranean basin, flash floods coming from the Sahara are now settling in northern Africa and the Mediterranean basin. Today, the Mediterranean climate is in a transition phase toward the Saharan climate; we are talking about Saharization. The wadis of North Africa tend to enlarge their sections to allow the quantity of water imposed by torrential rains to be evacuated. This process of widening sections of the wadis produces tons of mud following the phenomenon of erosion (Fig.

24 a and b). In addition to the undermining of the wadi banks, new gullies form in the watersheds (Fig. 25).

a) Undermining of the banks in Wadi of Labiod (Photo. Remini, November 2023)

b**) Undermining of the banks in the El Hammam wadi (Photo. Remini, 2014)**

Figure 24: Undermining of wadi banks in Algeria

Figure 25: Flash floods carve new gullies in watersheds (Photo. Remini, 2015)

In total, significant quantities of mud are transported by the wadis toward the sea and the dams. Quantities of water supposed to have fallen over the course of months, today they fall in a few hours. For example, the width of the Sahara wadis even exceeds 1 km.

FLASH FLOODS AND SILTION OF DAMS

After a long period of drought of 5 to 7 months, the soil becomes very favorable to erosion since the soil becomes friable and the particles are easily detached under the effect of water or wind. The short wet season characterized by torrential rains that fall on such soil inevitably leads to intense erosion of the watersheds and the banks of the wadis. The flash floods that have been recorded in recent years in the countries of North Africa and the Mediterranean basin have been very heavy and sometimes even drain muddy flows. This proves that flash floods deepen and enlarge the wetted sections of the wadis. There are even new gullies that have been carved into watersheds. With this large mass of mud, flash floods too loaded with fine particles arrive at the entrance to the dam reservoir. The contact of the two fluids of different densities causes the appearance of a density current that propagates on the bottom of the dam and below the clear water without any mixing (Fig. 26).

Figure 26: Propagation of density current in a rectangular channel **(Photo Remini, 2015)**

These density currents arrive easily with a very high concentration at the foot of the dam; operating the gates at the appropriate time can minimize the siltation of the dams. Otherwise (closed valves), the density currents trapped at the bottom of the dams release the fine particles that settle; this is the accelerated siltation of dams (Fig. 27).

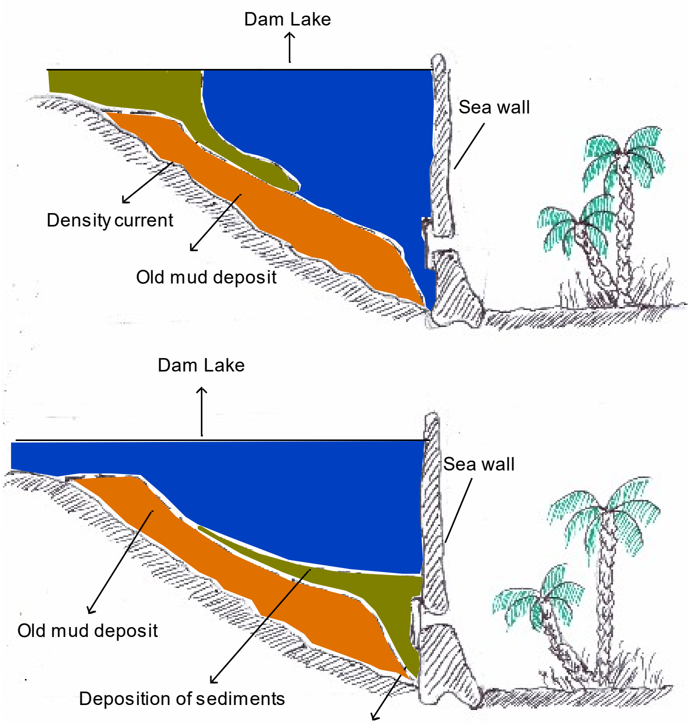


Figure 27: Diagram of the mechanism of density currents at the bottom of a dam (Diagram Remini, 2023) (Remini, 1997; Remini et al., 1995)

To demonstrate the extent of siltation and the solid inputs brought by flash floods at a dam, we began an experiment on the ancestral Tiout dam. In 2017, the reservoir was silted up with a volume of 10,000 m^3 of dust, i.e., a volume of more than 60% of the initial capacity (16,000 m^3) (fig. 28a). In 2018, the dam was devastated by mechanical means (dry devastation) (fig. 28b). During the second half of 2018, a flash flood occurred in Wadi of Tiout. Surprise the dam was silted up again; the same quantity of silt drained by the flood was deposited and occupied the initial surface of the reservoir, i.e., a volume of 10,000 m^3 (Fig. 28c). This proves that when a dam is devastated, approximately the same quantity of mud returns to its initial position during the next floods. On the other hand, this experiment demonstrates the significant quantities of mud drained by flash floods. This can only be explained by the enlargement of sections of the wadis by the effects of flash floods. We are talking about the resizing of hydrographic networks that are undersized compared to these flash floods.

a) Tiout Dam silted up in 2017 (Remini, 2022)

b) Tiout Dam devastated in 2018 (Remini, 2022)

c) After passing a flood, the Tiout Dam finds itself silted up again with the same quantity of mud removed (Remini, 2022)

Figure 28: Tiout Dam - Devastated then silted up by the same quantity of mud

FLASH FLOODS AND EVACUATION SYSTEMS

Today, rainwater evacuation systems (sanitation networks and flood spillways) are becoming undersized in the face of flash floods. Indeed, over the last 20 years, we have observed that the flash floods that have occurred in Algeria and in the countries of the Mediterranean basin are characterized by a rapid rise in the water level in the rivers. This led to catastrophic flooding in several cities. The sanitation networks of these cities were unable to evacuate the large quantities of water brought in by the flash floods. The flow rate of these new floods is greater than the evacuation flow rate. The same situation was repeated on the Foum El Gherza dams in 2011 and that of Derna (Libya) in 2023. Following flash floods, which appeared successively on the Labiod and Derna wadis. For the first dam (Foum El Gherza), the flood with a flow rate of 1600 m^3/s, the spillway incorporated in the dike could not evacuate all this mass of water, and the water will end up surpassing the dike above the crest of a blade of water of approximately 6 m. Fortunately, the V-type dam is able to withstand this exceptional phenomenon. For the second Derna dam, the flash flood of September 2023 could not be evacuated by the Tulip-type flood spillway, and the water will end up flowing above the rock-type dike. Unfortunately, the dam was washed away by the flash flood waters.

These two cases of overflowing floodwaters, whether at the level of cities or at the level of dams, will become a common phenomenon in the immediate future. It should be remembered that in recent years, several cities in Algeria have recorded exceptional flooding, and as a result, many neighborhoods found themselves submerged by water. No sanitation network has managed to evacuate the considerable masses of water drained by these new floods. Today, we can confirm that current sanitation networks are not immune to this new phenomenon. The same situation of water overflowing is repeated at the level of water dams, and hill reservoirs and dams will not be spared by flash floods. As we mentioned previously, these new floods, in addition to significant quantities, drain a considerable mass of mud; this is one of the characteristics of these flash floods. The deposition of sludge in sanitation pipes is becoming a major handicap for the design of sanitation networks in the immediate future. Indeed, the unitary type sanitation network is widely used in all the wilayas of Algeria. In our opinion, this type of network does not adapt to these new flash floods because it is incapable of evacuating the waters loaded with a flash flood. As we mentioned previously, the liquid and solid inputs intervene together in the dimensioning of the sanitation network. The sewerage pipe must be oversized based on the liquid flow brought by the flood, while taking into account the quantity of sludge that will be deposited in the pipe. After the flash flood passes, drought returns to the region, and the flow in the pipeline returns to its initial low flow position. The silt deposits settle and consolidate; the pipe once again becomes undersized and incapable of evacuating the waters of the next flash flood. The depth of the mud (H) becomes greater than that of arrow (a), and the pipe risks cracking and even bursting (Figs. 29 and 30a and b). We are in the case of a transition from a free surface flow to a flow under load.

Figure 29: Sanitation networks are today undersized in the face of the flash floods occurring in Algeria (Photo. Remini, 2023)

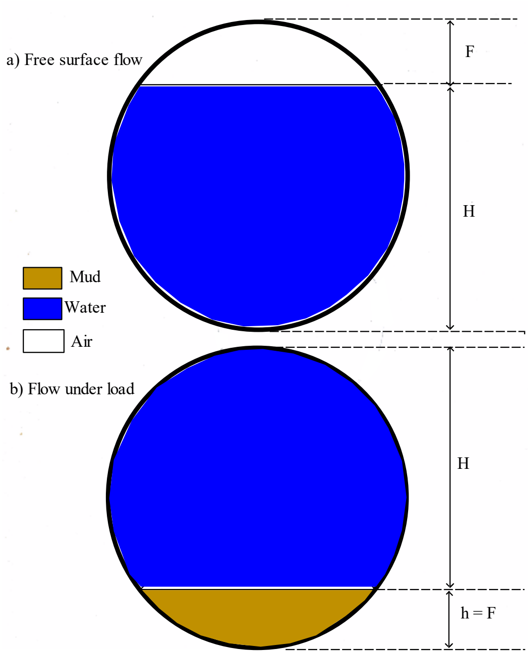


Figure 30: Unitary network: with flash floods, it is the transition from free surface flow to loaded flow (Diagram Remini, 2013)

Concerning, the inability of flood spillways to evacuate excess water from a dam caused by the rapid rise in the water level (following the arrival of a flash flood) poses a serious problem. Attention given its seriousness. The case of flooding in the city of Derna (Libya) caused by the flood of September 2023 attracted our attention. Given the scale and brutality of the flood that occurred on the Derna wadi, the waters submerged the two dams built on the same wadi. For us, it is a flash flood caused by storm Daniel that appeared during the night of Sunday 2023. It only takes 36 hours to see the equivalent of 12 months of rainfall in the Derna region. The entire volume of water that should fall in a normal year, the equivalent of 230 mm, fell in 36 hours; It's an enormous quantity! Although it has not been evaluated, the flow of the flood was historic since the flood surpassed the dike. The flood spillway is undersized in the face of this historic flood, and consequently, the water flows over the crest of the dam. Unfortunately, the rock dam did not withstand the strong flood, and as a result, the dam gave way. This Derna phenomenon can be reproduced on other dams in North Africa and south of the Mediterranean Basin. However, the Derna dam is not the first dam in the region to suffer a flash flood. The Foum El Gherza dam (Algeria) withstood the largest flood, which occurred in October 2011 in its history (more than 70 years). It is an arch dam equipped with a spillway incorporated into the body of the dam. It should be noted that the flood was well managed by the dam team from its arrival until the end of this natural disaster without suffering material or human damage.

The historical flood of 2011, which occurred on the Labiod wadi, remains the most dangerous flood in the entire Algerian hydraulic history given its brutality, the quantity of mud drained, and its flow rate estimated at more than 1600 m^3/s. The Labiod River, 120 km long, going from the heights of Chelia (the Aurès Mountains) to the site of the Foum El Gherza Dam (located 15 km before reaching the town of Biskra), is characterized by large variations in slopes. It should also be noted that the section of Wadi of Labiod is complex since its width varies from one point to another. For example, the width of the Labiod wadi varies from 20 m (the Mchouneche canons) to 500 m (Lehbel region). The 2011 flood traveled 120 km to reach the Foum El Gherza dam with a flow rate of 1600 m^3/s and very heavy water. This is how when the flood arrives at the tail of the dam, the contact of the water loaded with the flood with clear water from the reservoir generates the formation of a density current that spreads on the bottom of the basin and under the water of the reservoir. The water level of the lake is rising rapidly. Once the body of water reaches the level of the dam spillway, the excess water flows into the wadi, but the body of water is unable to stabilize (Fig. 31).

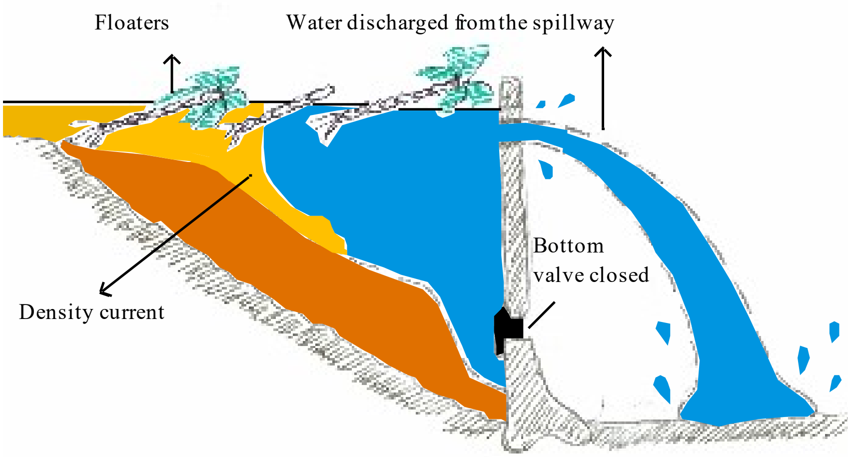


Figure 31: Probable diagram of spillway discharge (Diagram Remini, 2023)

In this case, operating the bottom valve becomes an essential operation. Quantities of silt flow at full speed through the bottom valve, but the body of water continues to rise and

cannot stabilize (fig. 32). Although the flood spillway and drainage channels operate at the same time, the lake water body cannot stabilize.

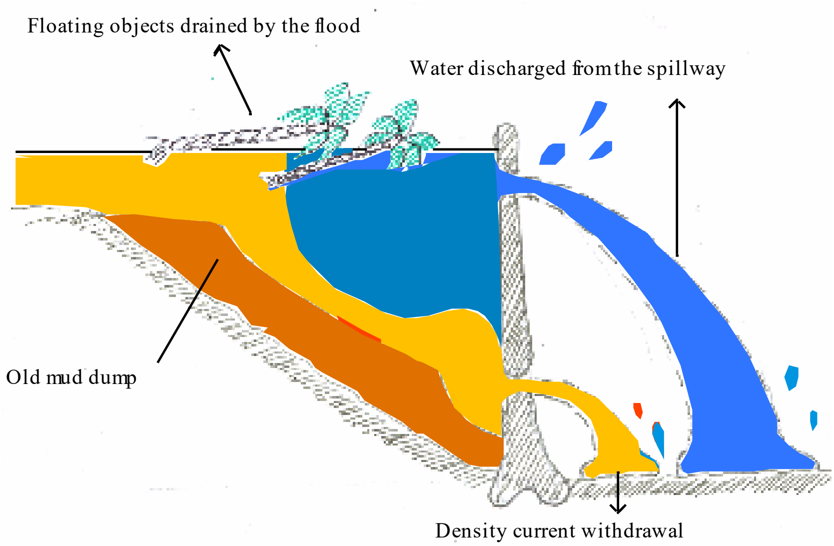


Figure 32: Diagram of spillway discharge and water evacuation through the bottom valve (Diagram Remini, 2023)

The flood loaded with fine particles increasingly occupies the space of the reservoir, and the flood spillway continues to evacuate the calibrated water from the reservoir (Fig. 33).

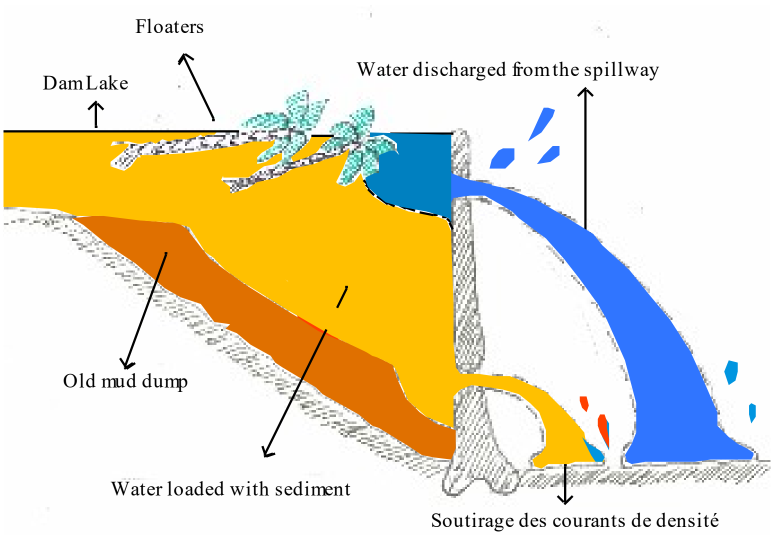


Figure 33: Diagram of the occupation of the volume of the reservoir by the waters loaded with the flood. The discharge of the clear waters of the renewal

has come to an end. The bottom valve continues to evacuate the density current (Remini diagram, 2023)

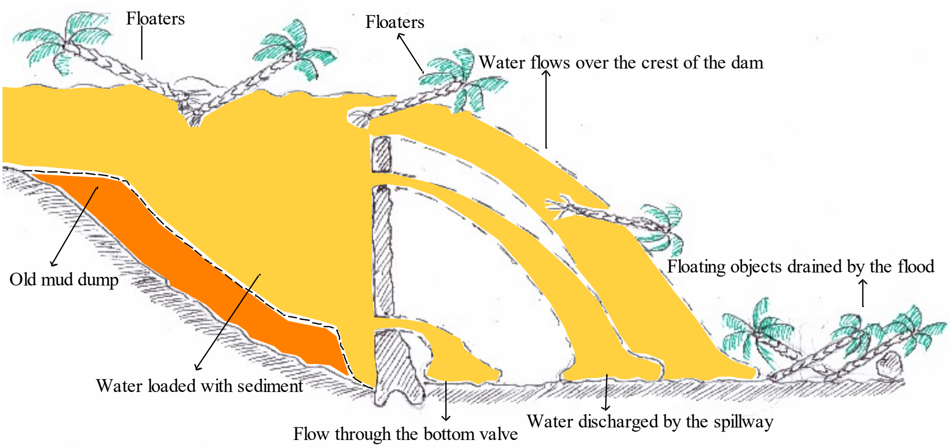


Figure 34: Diagram of 3 spills at once: through the spillway, through the bottom gate and on the crest of the dam (Diagram Remini, 2023)

a) Eau de la crue de 2011 **b) Eau de la crue 1994**

Figure 35: The high degree of concentration of fine particles from the 2011 flood compared to the 1994 flood where the water is clear (Photo National Agency for Dams and Transfers)

After this spectacular image, the water level of the lake gradually returned to the normal level of the reservoir, and the bottom valve was closed. Everything went well, and no problems were recorded. However, it is important to specify that the flood was exceptional; the volume of silt deposited in the reservoir was estimated to be more than 50% of the total capacity of the dam. Such a quantity of silt, estimated at 25 million m^3, had a significant influence on the filling of the lake when the flood arrived. The discharge of charged water from the three staged channels (on the crest, by the flood spillway and by the bottom gate) made it necessary to clean the entire downstream part of the dam (fig. 36)

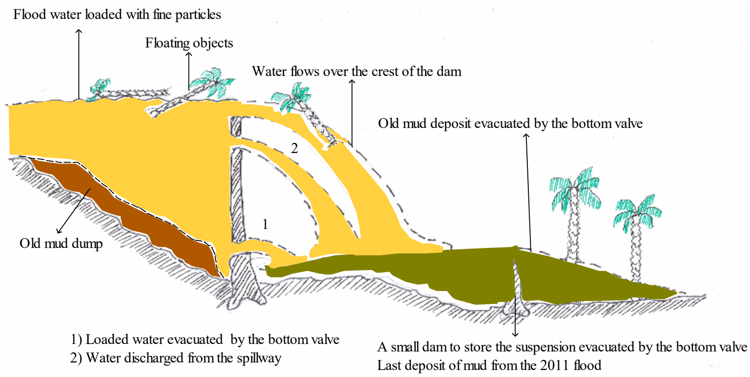


Figure 36: The small dam is under the mud coming from the releases of the dam (Digram Remini, 2023)

This is how a small dam reappeared. It is a dam that has been hidden under the mud for several years following the periodic withdrawal of the silt through the drainage channels. The dam was intended to store the quantities of silt evacuated by the bottom valve (Fig. 37). After settling, compaction and consolidation, the clear water recovered can be used for irrigation by farmers in the region.

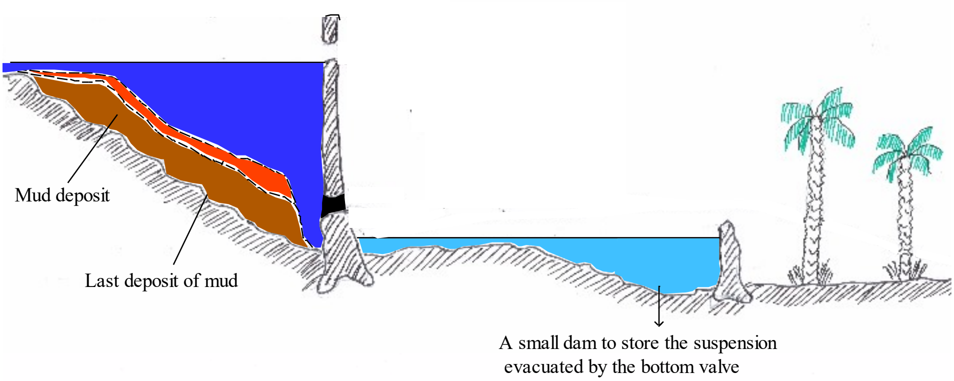


Figure 37: Thanks to the 2011 flood, the small dam is back in service (Diagram Remini, 2023)

To minimize the damage caused by flash floods, solutions must be taken by the services concerned. Concerning the sewerage network, the separated system is the one that adapts best to flash floods. Concrete and waterproofing must be replaced by the multiplication of urban forests. Regarding dams, the spillway must be oversized or add a second spillway to allow the flash flood to be evacuated. The construction of new dams must be performed with the addition of an elevation and a battery of gates for the withdrawal of turbidity currents (Fig. 38).

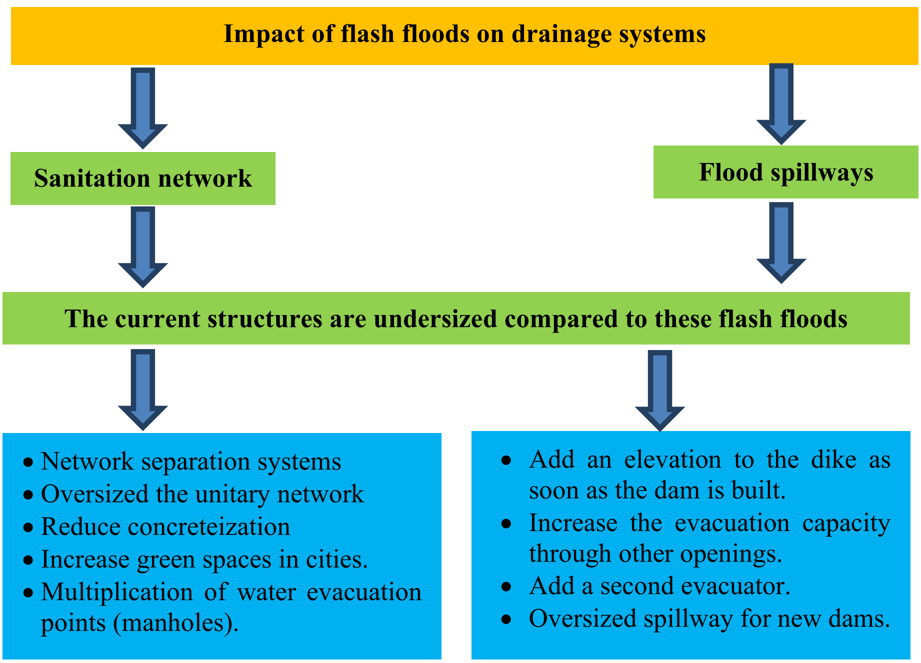


Figure 38: Short-term solutions to flash floods

DISCUSSION

Climate change is caused by the decrease in precipitation and the rise in temperature; therefore, evaporation also increases to reach record values. This produced a long-lasting drought followed by a short duration of flooding. This has direct repercussions on rivers and wadis. The decrease in rain and the splitting of snow were caused by a long drought. Such a situation leads to the drawdown of the water table and even the depletion of the water table if the drought persists. The arrival of torrential rains causes sudden floods to produce formidable floods. As a reminder, a river is a watercourse whose flow is continuous throughout the hydrological year, but the flow decreases during the summer season. The river is fed by rain during the fall and winter seasons, except that during spring, the river is fed by rainwater and drifting snow. During the summer, even if there is no rain, the river is fed by snow cracks. On the other hand, a wadi belongs to an arid region, and the flow is intermittent and is fed by sporadic and sudden floods that appear just after a long dry season. As soon as the flood subsides, the flow disappears. Except in certain cases, or the passage of a flash flood but with a significant flow, we can witness a flow of a liquid trickle that will evaporate over a few days. Today, in certain regions of the planet, particularly North Africa and the Mediterranean basin, we are witnessing a conversion of rivers toward wadis. What has happened in recent days in Italy and, more particularly, in the Emilia-Romagna region, in northern Italy, is hardly original. A sudden flood caused deadly floods. Approximately 36 hours were enough to obtain precipitation of 200 mm of rain on average in the most affected region and 500 mm locally, as reported by the Italian press (Le Parisien-Environnement, 2023). Spain has been affected by climate change. In recent years, this country has suffered repeated droughts, followed by torrential rains and floods. According to the Spanish Meteorological Agency (Amet), Spain experienced the hottest and driest month in April since weather records began in the country. This heat wave followed several months of drought, after a year 2022 considered the hottest in recent Spanish history (Libération, 2023). In some regions of Spain, up to 100 liters of precipitation per square meter accumulated in a few hours (Meto and Radar, 2022). This heat wave followed several months of drought, after a year 2022 considered the hottest in recent Spanish history (BFMTV, 2023). What has happened in recent years in the Mediterranean basin in terms of flooding calls for scientists and managers to act quickly and urgently on the hydraulic and environmental levels. What we have observed is that indeed today, the climate is no longer like before; a four-season climate. What is emerging today is the following formula: “Very long periods of drought followed by very short periods of intense rain which produce raw floods”. This weather pattern can be temporary or permanent. In certain regions, forest fires occur just after droughts (with extreme temperatures) and before floods. These new floods are characterized by the importance of the water transported and the mud carried in just a few hours.

- These new floods are sudden or even lightning floods and are due to very violent and localized stormy rains. They are characterized by a very rapid rise in water levels and occur in catchment areas of medium or even large surface area. Based on the exceptional floods that have occurred over the last 20 years in the countries of North Africa and the countries of the Mediterranean basin, we have highlighted the main characteristics of the new floods:
- Flash floods occur during the period from April to November.
- All these flash floods occur just after a drought characterized by very high temperatures, and even in some cases, fires break out just before the onset of floods and flooding.
- Flash cures are the cause of torrential downpours that fall within a few hours. Generally, 24 to 48 hours fall the equivalent of 3 to 12 months of rainfall during an ordinary season and in the same region.

- These new floods are characterized by brutality and speed and are driven by an exceptional flow force that can carry away all the obstacles (natural and artificial) existing in their routes.
- New floods drain water laden with fine particles and are yellowish or blackish in color depending on the nature of the rock. These floods carry floating objects of all kinds, namely, tree trunks and animal corpses. These floods also carry coarse material to the bottom of the wadi, including blocks, pebbles and gravel. We sometimes witness muddy flows.
- These new floods sculpt, erode and shape the section in the nonrocky sections of the watercourse.
- These floods create the phenomenon of “waves” during the flow, which is explained by the stopping and blocking by floating objects: tree branches and animal corpses and others. Such a phenomenon creates a slowdown in the flow and a rapid rise in water, which creates pressure on the barrier of floating bodies. The latter gives way and creates a shock wave that causes a wave similar to a water hammer in a closed pipe.

What we have noticed over the last 20 years is that during deadly floods caused by torrential floods in the North African and Mediterranean regions, the rise of water in the neighborhoods of flooded cities was rapid. This explains why the rainwater drainage networks are unable to evacuate the volume of water that has fallen on the region. In other words, the input flow (into the drainage system) into the city is greater than the output flow through the drainage system. This does not mean that there is a sizing problem. In reality, today, evacuation systems as well as sanitation networks are under stress in relation to new floods.

The same observation can be made on reservoir dams. Indeed, these new floods, which have occurred in several watersheds in North Africa and the Mediterranean basin, have significant flow rates. In reality, these values do not exist in the archives of hydrologists. This is not to say that such floods have never occurred in these watersheds, but there is a possibility that these floods occurred before the records appeared. Therefore, the question that arises is what is the return period of these new floods? Are we going to see a reduction in the return period or not? What happened at Wadi of Derna could happen again at other dams. Indeed, the Derna dam, which was washed away by the flood of September 2023, was not the victim of a technical error, but in reality, the flood spillway is currently undersized compared to these new floods and may be floods that appeared well before the arrival of the archives.

The new floods appear just after a long drought of 5 to 6 months marked by heat where the thermometer indicates temperatures exceeding 40°C. The latter lifted considerable masses of water toward the atmosphere but in the form of vapor. Stored in the sky then through the process of condensation. These quantities of water fall in the form of rain but with exceptional intensity. These floods, which are sudden and especially devastating, are called flash floods. Such floods are not new, but this phenomenon often occurs in arid environments and more particularly in the Sahara. In such an environment, there is no average, there are no low water levels, and there are only extremes that result in peaks. These floods in arid environments, today called flash floods, have sculpted and shaped their routes, which are the wadis. It has been eroded, dug and sized to transport these large bodies of water. This is how we find that the section of the Sahara wadis is a wide section whose width even exceeds 1 km like that of Mzab, Zerhoun, M'Zi... Without two beds (minor and major), the Sahara wadi is a wadi with a single very wide bed that allows an immense flow of water to flow in a few hours. Obviously, the mass of water transported is divided into 3 parts; one (the largest) evaporates to reach the atmosphere. The second flows over the bed to reach its drop point, which can be an Erg, a freshwater lake or a chott. The third part flows under the bed and infiltrates to reach the natural reservoir.

Today, with climate change, rivers in the countries of the Mediterranean basin are converting into wadis. That is, the continuous flow of water no longer appears in the watercourses, giving way to a discontinuous flow. This is due to the low rainfall and especially the scarcity of snow, which ensures the sustainability of the rivers in summer periods thanks to the splitting of snow during the spring season. This whole process only summarizes the first phase of transformation of a river into a wadi. The second phase is the most complex because it will be marked by the brutality of the floods, which will cause high intensity erosion of the watersheds and especially the erosion of the banks of the wadis themselves. This is the stage of resizing the section of the new wadis, that is, the new sections that correspond to the new liquid intake. Over the last 50 years, these flash floods have been marked by the presence of a large quantity of solid particles carried by the wadis. The mud transported by the wadis has become a characteristic of these flash floods, which appear in the countries of North Africa and the Mediterranean basin. This is explained by the sections of current watercourses that cannot carry as much water as that brought by current flash floods. Quite simply, the sections of these watercourses are not designed for this type of flow. Therefore, we are in a stage of resizing the watercourses; it is the widening of the sections to be closer to those of arid regions.

The watercourse carries large quantities of sediments and floating objects, which results in strong erosion of the bed and deposition of transported materials. These can form dams, called ice jams, which if they break, release a wave that can be very dangerous. The very rapid rise in water levels during a flash flood can also suggest the arrival of a “wave” (PCMR, 2020). Very long periods of drought and very short periods of intense rain” This term “tropicalization” is often used in the Mediterranean area according to Italians. For us, we are talking about Saharisation. Climate change has reached Italy, and this process of tropicalization accustoms us to very long periods of drought and very short periods of intense rain (Le Parisien-Environnement, 2023).

CONCLUSION

As we mentioned at the beginning of this article, flash floods are of Saharan origin. Under the effect of climate change, flash floods have moved toward northern Africa and then toward the southern Mediterranean basin. These flash floods carry water loaded with a high concentration of solid particles. This is the work of resizing hydrographic networks and digging new ravines. It should also be noted that these new floods appear just after a long period of drought. With exceptional tractive power, flash floods remove all the existing obstacles on their routes. These new floods are called flashes because of the rapid rise in the water level in the wadis due to a quantity of water supposed to fall in 3 to 12 months, but it fell in 24 hours to 48 hours. This particularity of flash floods resulted in the inability of rainwater evacuation systems to adequately perform their function. Whether it is the sanitation networks or the flood spillways of the dams, these two hydraulic safety structures are currently undersized in the face of flash floods.

Three major events have marked the history of flash floods in Algeria. The first event was marked by the flood of the first of October 2001, which occurred on the ‘Koriche River. With a flow rate of 750 m^3/s, this flood drained an exceptional quantity of mud exceeding 1 million m^3. The second event was marked by the month of October, which recorded several flash floods that appeared in the wadis of southwest Algeria, notably that of the Mzab River and that appeared on the Bechar River. The last event corresponds to the flood of November 2011, which occurred on the Labiod River. This exceptional flood with a flow rate of 1600 m^3/s flowed over the crest of the Foum El Gherza dam, but without damage, and the dam is still operating. What has happened over the last 20 years in Algeria and the Mediterranean basin in terms of flooding calls on scientists and managers to act quickly and urgently on the hydraulic and environmental levels. Flash floods remain an original subject and deserve in-depth studies to better understand their appearance and mechanisms and why they are not able to anticipate floods.

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

This modest paper is the culmination of field work that lasted 30 years. Data that have been measured and collected over the years. Photos that were taken at random and discussions that took place with farmers and the Ksourian population. Sahara floods; a subject that has fascinated me since a young age. One day witnessing the passage of a flood in a dry wadi was my wish. In 2004, as if by chance, I witnessed the filling of the Beni Izguen dam by a flash flood that appeared on the Nssa River. In 2006, a sudden flood that occurred on the Labiod wadi allowed the flood spillway to discharge excess water from the lake from the dam. Today, with climate change, everyone is talking about flash floods but without giving details. After studying a few articles on flash floods, I noticed that ultimately they are only Sahara floods. It was the trigger for me to prepare this modest paper. So I would like to sincerely thank everyone who helped me in any way. A big thank you for the entire Ksourian population of Ziban, Souf, Saoura, Touggourt, Touat, Gourara, Tidikelt, Tamanrasset, Djanet, Ouargla, Ain Sefra, Tiout, Boussemghoun, from Asla…

Thanks to these studies, I discovered a fascinating world: SAHARA.

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