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FLOODS AND SILTATION IN SOME AURESIAN WATERSHEDS (EAST OF ALGERIA)

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EXTENDED ABSTRACT

Questo lavoro si propone di analizzare le inondazioni e l'interramento delle dighe in due bacini le cui caratteristiche litologiche, idroclimatiche e topografiche variano nettamente, attraverso un approccio comparativo che confronta le piene secche e umide dei due bacini e lo studio degli idrogrammi per l'iterramento. Si confrontano i rilievi batimetrici e i calcoli effettuati utilizzando formule empiriche ampiamente utilizzate in Algeria (F. Orth, Woodburn).

Il massiccio dell'Aurès fa parte dell'atlante sahariano orientale dell'Algeria. La sua evoluzione è strettamente legata alla fase post-lutetiana, che rappresenta la principale fase tettonica nell'area di studio. Inoltre, sono presenti diverse formazioni geologiche impermeabili in particolare nel nord del massiccio (bacino idrografico della Chemora) dove marne e argille, che si trovano principalmente a quote medie e in pianura, costituiscono formazioni erodibili che contribuiscono allo sviluppo di diverse forme di erosione e inondazioni a causa della loro bassa infiltrazione. I versanti esposti a nord sono i più ricoperti di vegetazione e i meno interessati dall'erosione e allo stesso tempo assistono a inondazioni più attenuate; d'altra parte, il bacino del wadi Labiod si trova sul versante meridionale del massiccio più ripido, caratterizzato da formazioni di calcari, arenarie, marne e formazioni quaternarie più vulnerabili all'erosione e presenta una dinamica fluviale molto attiva che si manifesta con l'erosione laterale e verticale dei wadi, la formazione di canaloni e inondazioni irregolari, rapide e violente che producono abbondanti sedimenti sotto il regime torrentizio più dominante.

Il flusso nel Wadi Chemora è caratterizzato da piene che creano un regime idrologico vario, irregolare e polifasico, caratterizzato da diversi picchi legati alle precipitazioni annuali, autunnali e talvolta primaverili con sequenze annuali simili in abbondanza o deficit e forma degli idrogrammi molto monotona con una bassa risposta idrologica.

In generale, le piene durante il periodo umido sono le più aggressive e causano danni significativi all'uomo e alle infrastrutture, mobilitando volumi significativi di acqua e sedimenti che raggiungono i 9 hm^3 nel bacino di Oued Labiod. Entrambi i bacini terminano in dighe e l'interramento osservato è variabile e irregolare, con un tasso accelerato nella diga di Foum Elgherza e medio-basso nel tempo a Koudiat Mdouar. Foum El Gherza registra un tasso medio annuo di insabbiamento di 0.59 hm^3 con un volume massimo di 32.11 hm^3 nel 2001, dopo 50 anni di attività. Inoltre, l'ultimo studio batimetrico condotto presso la diga di Koudiat Médouar ha mostrato che il processo di interramento è basso e che il volume di limo non supera 1.3 hm^3 (Khentouche, 2011); la riduzione dell'insabbiamento in questa diga è dovuta principalmente alle azioni antierosive intraprese nel corso degli anni (rimboschimento, costruzione di bacini di sedimentazione).

Il regime idroclimatico delle piogge e dei flussi torrentizi, in particolare in autunno e in primavera, produce violente inondazioni cariche di sedimenti che contribuiscono all'accelerata sedimentazione della diga di Foum Elgherza, mentre la diga di Timgade presenta una sedimentazione relativamente bassa. Inoltre, il bacino idrografico di Wadi Labiod ha prodotto un trasporto solido specifico medio di 980 t/km^2/y, mentre il bacino idrografico di Chemora ha prodotto un'erosione di 670 t/km^2/y con il modello di Orth che fornisce risultati simili e comparabili a quelli ottenuti dai rilievi batimetrici rendendolo applicabile in condizioni climatiche, fisiche e litologiche simili. Secondo tale modello la sedimentazione può essere suddivisa in due classi:

- fase alluvionale elevata nei primi dieci anni di esercizio, con sedimentazione rapida e inferiore a 7.53 hm^3 per il bacino di Foum El Gherza e inferiore a 2.55 hm^3 per la diga di Koudiat Mdouar;
- fase di bassa sedimentazione dal 10° anno di esercizio fino al 25° anno, dove l'interramento è relativamente regolare, con circa 5 hm^3 ogni 7 anni nella diga di Foum Elgherza e 2.2 hm^3 ogni 7 anni per la diga di Koudiat Mdour.

La gestione dell'interramento richiede vari interventi biologici attraverso diverse tipologie di rimboschimento e interventi meccanici basati essenzialmente sulla creazione di bacini di sedimentazione, il sollevamento della diga e operazioni di dragaggio, rendendo pertanto necessario effettuare un'accurata diagnosi delle fonti di interramento esaminando tutti gli elementi fisici del territorio.

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ABSTRACT

This study showed the evolution of siltation and flooding in two watersheds of the Aures massif (Labiod and Chemora) which are located in the east of Algeria. according to a comparative approach which takes into account the comparison of bathymetric surveys and the calculations carried out by empirical formulas widely used in Algeria. The hydroclimatic regime of torrential rains and flow, particularly during autumn and spring, produces violent floods loaded with sediments contributing to accelerated siltation of the Foum Elgherza dam, however the Timgad dam shows relatively low siltation.

In addition, it is noted that the Wadi Labiod basin produced an average specific solid transport of 980 t/km^2/y while the Chemora watershed produced an erosion of 670 t/km^2/y. It is observed that F. Orth's model gives results close and comparable to those obtained by bathymetric surveys, which qualifies this model to be applicable in similar climatic, physical and lithological conditions. Siltation can be divided into two classes according to F. Orth's model:

- a high alluvial phase prevailed during the first ten years of operation, with rapid siltation of less than 7.53 hm^3 for the Foum El Gherza basin and less than 2.55 hm^3 for the Koudiat Mdouar dam;
- a low siltation phase began from the 10th year of operation up to 25 years, with siltation occurring relatively regularly, recording approximately 5 hm^3 of siltation every 7 years for the Foum El Gherza dam and 2.2 hm^3 every 7 years for the Koudiat Mdouar Dam.

Keywords: *dam, siltation, erosion, bathymetric surveys, comparative approach*

INTRODUCTION

The siltation of dams poses enormous problems for the reservoir. It leads to a reduction in the useful capacity of the dam and the blockage of the emptying devices, the degradation of the water quality and finally the stability of the structure (Remini *et alii*, 1997).

This study mainly targets the analysis and comparison of the evolution of siltation in certain dams located in the mountainous areas of eastern Algeria, characterized by physical and hydro-climatic diversity between their northern and southern slopes.

Flooding and dam silting are two interrelated phenomena that have direct impacts on the environment.

Mebarki (2010) showed that due to the rapid silting up, the reservoirs lost a lot of their initial capacity (2 to 3 per year on average), moreover Remini *et alii* (1997) pointed out that estimated sedimentation of the Foum El Gherza Reservoir as a polynomial function of time. Remini & Hallouche (2003) established two relationships giving annual sediment inflows as a function of operational time, a power function for Maghreb's reservoirs having a high sedimentation rate, and a linear function for those having a low rate (Tebbi *et alii*, 2012).

This contribution explains the current and future prediction situation of siltation through the adoption of a comparative method between mathematical models that are widely used in studies of estimation of siltation such as the method of Orth (1934) and that of Woodburn (1955) compared to the analysis of bathymetric surveys.

Several authors agree that siltation follows a potency pattern and develops differently over time depending on certain limiting factors (Brambilla *et alii*, 2015; Khanchoul *et alii*, 2012; Lahlou, 1990).

We mention that September and December have more floods.

Hot season floods generally linked to brief and localized thunderstorms, are characterized by a short duration; moreover, Autumn floods are the strongest, mobilizing considerable volumes of water (Bourouba,1998).

The hydroclimatic regime of rains and torrential flows, particularly in autumn and spring, produces violent floods loaded with sediment contributing to the accelerated siltation.

Demak (1982) showed that the climatic, geomorphological and hydrological characteristics of the labiod watershed give it rapid mobilization of flows.

The Foum El Gherza dam, located in the Oued labiod watershed the source of heavy sedimentation, mainly due to stormy rains that cause violent floods (Khentouche & Dridi, 2018; Bouguamouza *et alii*, 2020).

Several techniques and developments: biological (reforestation), mechanical (settling ponds, increasing the height of the water dam dike, dredging, implementation of torrential correction and creation of settling basins at the minor bed level and rapid reactivation of flood prevention plans, etc.) have been used in the management of floods and siltation.

It is necessary to make a careful diagnosis of the sources and factors of siltation and flooding.

In the end, we can say that the fight against siltation and flooding requires a priori knowledge and understanding of the factors and processes generating and accelerating this phenomenon (Megnounif *et alii*, 2003; Remini & Hallouche, 2003; Meddi, 2014) and there is a need to integrate anti-erosion measures before dam construction.

MATERIALS AND METHODS

The data used in this study come from the various bodies responsible for the management, control and monitoring of hydraulic projects:

- ONM (national meteorological office): source of rainfall data;
- ANRH (National Water Resources Agency) source of flow rates and rainfall data;

- ANBT: (national agency for dams and water transfer): Source of technical data and bathymetric surveys;

- (PNR) Research project entitled: Diagnostic Study of Siltation in the Koudiet Mdouar Dam sponsored by the Center for Scientific and Technical Research on Arid Regions (CRSTRA) and University of Batna 2, Algeria, 2010).

To determine the evolution of siltation in the studied dams over time we used the results of some bathymetric surveys carried out, during various periods, each survey interprets the behavior of the siltation in a phase. We have found it useful to make a comparative study between the results obtained by the two empirical relationships (Orth, 1934; Woodburn, 1955) and the results of the completed bathymetric surveys.

The choice is made in this study on these formulas which are justified by the fact that they are the most used relationships in Algeria (Saidi, 1991).

Many researchers rely on capacity to assess silting (Molino *et alii*, 2023).

Orth (1934) is among the first to study the prediction of siltation. He assumes that the residual capacity varies over time as a function of an exponentially decaying law.

The formula is widely used in Algeria for forecasting the volume of deposits, this formula applied to 16 dams in Algeria, the results of which are as follows:

- 56% of cases have an average absolute deviation <5%;
- 81% of cases have an average absolute deviation <10%;
- 18.7% of cases have an average absolute deviation > 10%.

The formula takes into account the change between residual and normal capacity over time and can be written as follows:

$$V_{st}=C_m-C_t \qquad (1)$$

where:

V_{st}: volume of accumulated sediments;

C_m: the normal holding capacity in hm³;

C_t: it is the residual capacity after t years of service in hm³.

Calculation of V_{st} requires knowledge of S_d and C_t.

Orth (1939) assumes that S_d=V=1 during the first year of operation, with:

S_d: the solid flow transferred to hm³.

SSL: the solid load of the specific degradation (abrasion rate) in t/km²/year.

t: the number of years;

Y_s: density of materials (m³);

A: catchment area (km²);

with residual capacity (C_t):

$$C_t=C_m*(1- S_d/C_m)^t \qquad (2)$$

$$S_d=(SSL*S*t)/Y_s \qquad (3)$$

According to Woodburn (1955):

$$S_p=2.492 *A^{0.9151} *S_t^{0.8303} *T_n^{0.7329} \qquad (4)$$

where:

S_p: sedimentary product (deposit retained in the lake in tones)

A: catchment area (km²);

S_t: quantity of erosion in t/ha/year;

T_n: years of service of the dam.

Study area

The two valleys concerned by this study are located in the Aures massif which is part of the Saharan atlas east of Algeria (Fig. 1).

The evolution of the Aures massif is well linked to the post-Lutetian phase. Furthermore, the geological formations are made up of several impermeable formations.

The Chemora basin is located on the northern slope of the massif characterized essentially by a vulnerable lithology consisting of Pliocene clays and Cenomanian marls, a folded and faulted geological structure, its drainage density is of the order of 2.60 km/km² and a torrentially of 26; the Chemora basin occupies an area of 672.7 km² and a perimeter of 148 km, it drains its waters towards Sabkha and Graat;However, the Oued Labiod basin is characterized by a very varied lithological facies, a faulty structure of steep slopes. Its area is around 1300 km² which drains its water towards Chott M'elghir, the lowest point in Algeria. This valley, which extends over 85 km in length, is well watered in its upstream part and brings together all the conditions favorable to the acceleration of erosive activity.

STUDIED DAMS

Foum El Gherza dam

This structure consists of two parts which are an arch of 126 m and an abutment of 60 m in length, its maximum height reaches 73 m and its initial capacity is of the order of 47 million cubic meters (S.E.G.G.T.H., 2001).

This structure is of great economic interest in the region since it makes it possible to irrigate more than 300000 date palms in the palm groves of Sidi Okba, Garta, Seriana and Thouda (S.E.G.G.T.H, 2001; Remini, 2017). However, it is reduced each year by a significant volume estimated on average at 5 million m³.

The bottom valve was evacuated from 1989 to 1993, 600000 m³ of silt in 1989, the valve was completely blocked by silt.

Early 2000, the Foum El Gherza dam recorded a cumulative siltation since 1950 exceeding 70% of its capacity.

Koudiet Mdouar dam

The Koudiet Mdouar dam is built on wadi Reboa, is located 7 km northeast of the city of Timgad, with the objectives of

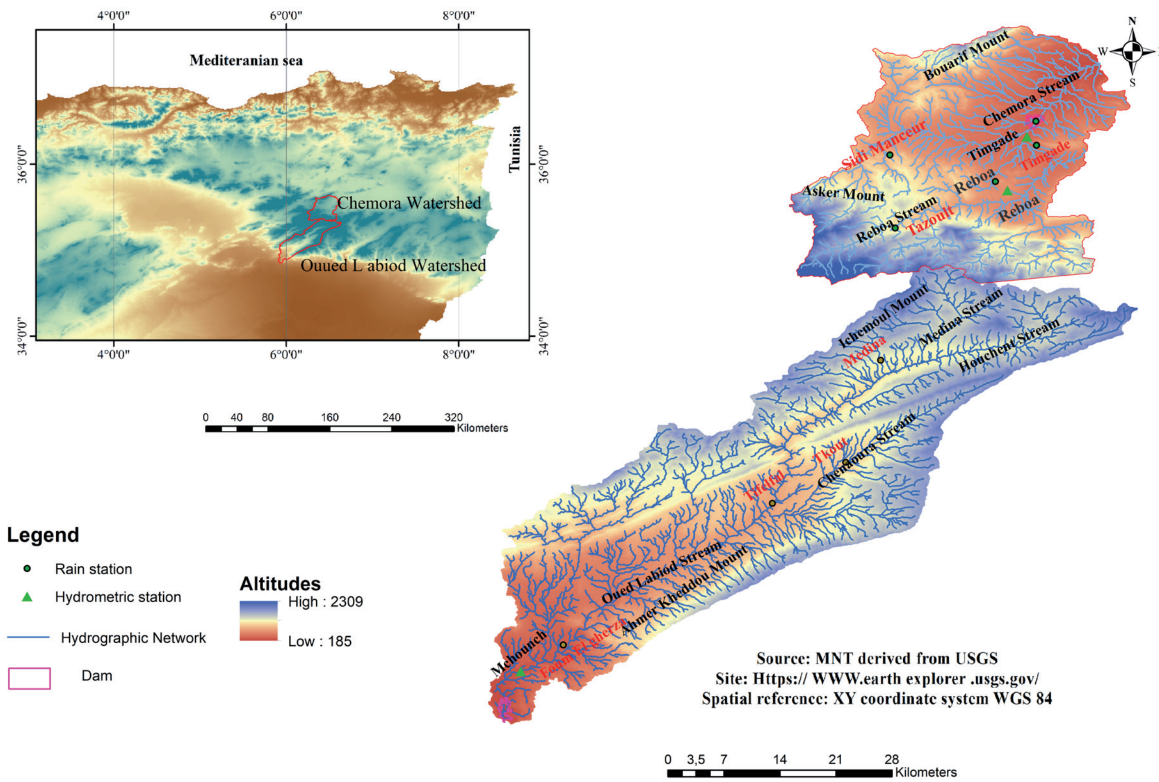

Fig. 1 - Location of the study area in relation to eastern Algeria

ensuring the drinking and industrial water needs of the cities of Batna, Khenchela and Ain Touta and also the irrigation of over 15700 ha of agricultural land in the plains of Batna, Chemora and Ain Touta.

Characteristics of the dam:

- core earth type;
- free surface spillway 2500 m^3/s;
- bottom drain gallery;
- height is 48 m;
- peak width about 10 m;
- initial capacity 74 (hm^3);
- impoundment 2003;
- destination: irrigation and drinking water supply.

CURRENT SITUATION OF SILTATION IN SOME DAMS

The table below provides information on the state of siltation in some dams in the massif in 2004.

ANBT in (Regional Report on the Management of Sediments in Dams in the Mediterranean - Regional Workshop December 13 and 14, 2010, Marseille, France).

It turns out that the observed siltation increases as a function of time for all the dams, while the Foum el Gherza dam records an average annual siltation rate of 0.59 hm^3 with a maximum volume of 32.11 hm^3 in 2001, or after 50 years of operation; note that the last bathymetric survey completed at the level of the Koudiet Mdouar dam showed that the siltation process is weak and the volume of the silt till 2011 was 2.5 h m^3 (Khentouche, 2011).

N°	Dam	Impoundment of The dam	Initial Capacity (hm^3)	Bathymetric survey	Average Annual siltation (hm^3)	Last survey or last estimate (hm^3)
1	F. El Gherza	1950	47	1967	0.59	13.72
				1975		18.46
				1986		23.86
				1993		26
				2001		32.11
				2004		
2	K. Mdouar	2003	74	2004	0.30	0.5
				2011		2.5

Source: ANBT, 2010.

Tab. 1 - The state of siltation in the dams studied

Variations in Average Annual Rainfall (Chemora and wadi Labiod)

The annual temporal distribution of rainfall in the two basins is shown in the figure below:

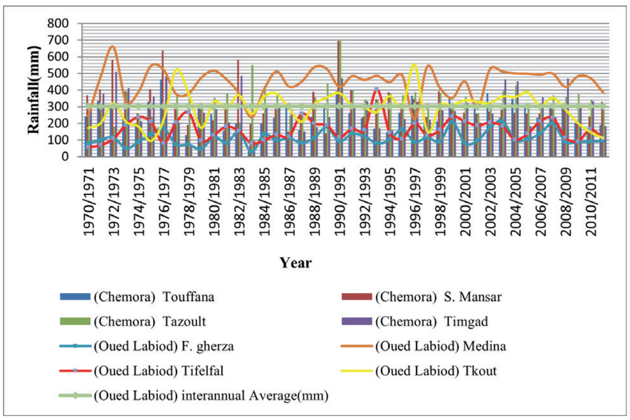

Fig. 2 - Annual rainfall variations for Chemora and wadi Labiod basin (1970-2012)

Annual precipitation

For the Labiod wadi basin, the lowest precipitation was observed at the Foum Elgherza station (28.5 mm) during 1984 and at Tifelfel station (58 mm) during 1971; these two stations are located in the downstream part of the wadi Labiod basin and are very close to the (hot) desert effects, all their average rainfall are lower than the interannual average (average of all the stations in the two basins) which reaches 302.81mm.

The Medina station, which is located in the upstream part of the wadi Labiod watershed, records values higher than the interannual average of the stations studied; it provides an annual average of 445.13 mm and a maximum of 650 mm during 1973.

Tkout station occupies the middle part of the basin which remains less watered and less wooded; receives 294.11mm annually; the more water in this area it receives the flows coming from the upstream part of Chemora basin.

The Tazoult station records the most abundant rainfall with an annual average of 347.9 mm. It is located in the upstream part of Chemora, its maximum is 427.5 mm and the minimum is around 207.5 mm.

21 years are higher than the interannual average; however, the Toufana and Timgad stations which are located in the downstream part of Chemora basin respectively give rainfall averages of 253.581 and 291.99 mm. lower than the interannual average.

Flow and floods

The hydrometric stations used are Reboa and Timgad for the Chemora basin and M'chouneche for the wadi Labiod basin (Fig. 1). The annual flow regime has shown clear irregularities between one year and another but there are sometimes some similarities in the flow values of the two basins which shows the general character of the rainfall and flow in the area particularly in autumn and spring when torrential rains produce significant runoff and flows. In many, cases we see the presence of similar temporal sequences which expresses a situation of abundance of flows (years 1980, 1981, 1982, 1983) or deficits (from 1990 until 1996) (Fig. 3); wet years whose runoff is above average and which are 17 wet years for the Chemora basin) and 15 for the wadi Labiod basin while the flow rates of the wadi Labiod are high compared to those of Chemora. This is the same observation for the average of each series of basins. The most numerous and significant max values are observed in the wadi Labiod basin (Fig. 3).

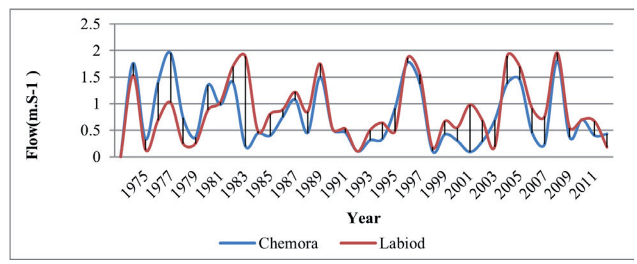

Fig. 3 - Variations in average annual flow rates at the stations of the watersheds studied

Floods

Floods are natural phenomena caused by forms of precipitation (Simona & Cedric, 2007; Ducrocq, 2006). They are linked to hydrological regimes and the characteristics of the watershed (Bravard *et alii*, 1997).

Certain watersheds of the massif belong to the pluvial regime or to the snow-pluvial regime. Flooding can be defined as a significant increase in the volume of water under the effect of runoff and rain.

Floods essentially depend on the abundance of rainfall intensity and distribution in the catchment area; the slope of the watershed and its vegetation cover accelerate the flow.

The structure and hierarchy of the hydrographic network, the specific morphology of the river bed accelerate the genesis and evolution of different types of floods (Chave, 2002; Niculescu & Lardeux, 2007; Nastoset *et alii*, 2013).

They occur during violent downpours and on steep mountain valleys, they generally develop in autumn under the effect of short-term orographic rains (4 to 6 hours) (Probst *et alii*, 1992). Moreover, the peak flows of this can be significant, exceeding 100 m^3/s (flood of 08/24/1978 at the Khanguet Sidi Nadji station Where Q_{jmax}=72.8 m^3/s).

Widespread heavy flooding

They, generally, occur during winter, spring and more particularly during the months of February and March: they are caused by relatively regular, continuous precipitation whose intensities remain very variable.

The majority of these flows become likely to have a significant effect on erosion and more particularly those which contribute to the shaping and evolution of watercourse beds. These floods are capable of undergoing very significant fluvial morpho-dynamic variations and can practically participate in the processes of sedimentation of dams. The floods of the Chemora basin mainly come from the Reboa wadi.

They are especially autumnal (between September and November) with sometimes a return to the spring season beginning of the summer season (from March to June). On wadi Reboa, the flood of 20 September 1997, recorded a maximum flow of 250 m^3/s and a total volume of 4.7 hm^3, which corresponds to 69% of the monthly intake and 14.4% of the annual contribution.

The volumes of some floods observed between 1953 and 2004 vary from 0.1 hm^3 (27/05/1989) and 9.39 hm^3 (11/11/1982) (Table 2); On 14/03/1996 another major flood of 153 m^3/s generated by a rain of 200 mm which lasted 24 hours it volume was 1.7 hm^3 this cold season flood was characterized by several peaks which are explained by the difference in volume of the flow coming from each sub-basin, is Influenced by the irregularity of the rains; the summer floods are in turn important, they are frequent mainly on month of June exceptionally, they can occur in August like the one recorded on August 12, 2002 with a maximum high flow of 119.2 m^3/s, or 386.3 $l/s/km^2$ and a total volume of 0.7 hm^3, which represented 65.5% of the monthly intake and 3.9% of the intake annual at the Reboa station.

A single strong maximum flow (139.6 m^3/s) formed on November 11th 1982 in wadi Guergour had quoted 3.1 meters at 7:30 a.m; this flood had lasted 35.5 hours between November 10 and 12. It had a volume of 9.39 hm^3 and represented 98.7% of October monthly supply (Table 2).

	Dry season		Wet Season		
Date	Volume of flood (hm^3)	Max Flow (m^3s^{-1})	Date	Volume of flood (hm^3)	Max low (m^3s^{-1})
25/05/1972	0.56	129	11/11/1982	9.39	139.6
27/05/1989	0.1	286	21/01/1996	1.5	50
12/08/2002	0.7	119	14/03/1996	1.7	153
31/07/1994	0.6	135	20/09/1997	4.7	250
			29/04/2001	1.6	150

Tab. 2 - Point flows and flood volumes observed in the Chemora watershed at the Reboa station

The Fig. 4 provides data from certain floods recorded in the wadi Chemora valley.

The hydrograms illustrated in the Fig. 4 express clearly varied hydrological behavior.

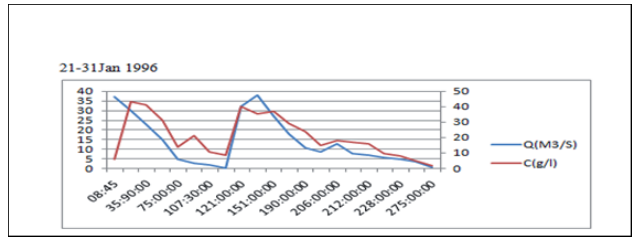

Fig. 4 - Floods recorded in the Wadi Chemora valley at the Timgad station

The flow presents a varied, irregular, polyphasic regime characterized by several peaks. The shape of the hydrograms turns out to be very monotonous.

Concentrations and instantaneous flow rates reach maximum values at the same time; in this case we speak of approximate concordance between erosion and transport after a duration which generally coincides with the concentration time.

The hydrogram of the flood of January, 31, 1996 has revealed two different phases:

- the first phase is relatively short characterized by a weak agreement between the concentration and the max flow rate; in this phase the flow is favored by the successive mobilization of rainwater from several tributaries, the curve is characterized by a maximum flow of 45.5 m^3/s, a max concentration of 35 g/l over a period of 12 hours and 20.

- the second phase is relatively long in which the maximum flow rate is of the order of 48 m^3/s and the concentration was 32 g/l so the flows take a long time (45 hours).

The concentration increases slowly and decreases in the same way to give a staircase shape. However, for certain hydrographs, the extreme concentrations arrive later than the peak flows (Bougamouza *et alii*, 2020); this situation can be explained by the slow mobilization of sediments probably under the effect of the competence and power of the watercourses.

Hot season floods, generally linked to brief and localized thunderstorms, are characterized by a short duration.

This remarks were very similar to the results obtained in this work, the floods of wadi Labiod (Table 3) are very violent and sudden and of short duration, since they come either from local storms in Summer or, from Saharan depressions, in Spring and even more often in Autumn (Fartas *et alii*, 2017);

	Dry Season		Wet season		
Date	Volume of flood (hm^3)	Max Flow (m^3s^{-1})	Date	Volume of flood (hm^3)	Max flow (m^3s^{-1})
			06/09/1953	9.1	212
29/08/1984	2.8	250	03/10/1982	3.3	182.5
27/05/1989	2.5	291.4	03/11/1982	2.7	118.6
31/07/1994	1.3	135	20/091989	3.7	297
05/05/2004	2.7	200	20/09/1997	4.7	250
04/05/2006	5.2	207	15/04/2004	2.8	250

Tab. 3 - Point flows and flood volumes observed in the wadi Labiod watershed at the M'chouneche station (Source: ANRH)

The month of May 2006 marked the presence of a significant flood with a volume of 2.7 hm^3 and a peak flow of 200 m^3/s which caused very remarkable damage to agriculture and infrastructure.

This widespread flooding of 4/03/May 2006 had varied effects on some towns Arris, Inoughissen, Ghassira and Tkout.

The month of August is characterized by showers generating significant flooding, for example the flood of 29/08/1984 which gave a volume of 2.8 hm^3 and a point flow of 250 m^3/s. We can observe that cold season floods occur mainly in autumn and April (Balla, 2017; Benkhaled *et alii,* 2013; Mebarki, 2005).

In September of 1997 a flood volume of 4.7 hm^3 with a flow rate of 250 m/s recorded at M'chouneche station.

The flood of (03/10/1982) was very important that its flood max reached 183.5 m^3/s and it flood volume was 3.3 hm^3 it gave a high sediment load about 92 g/l (Fig.5).

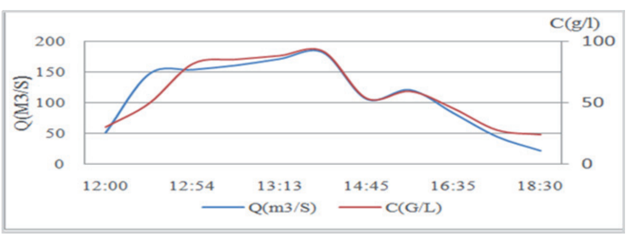

Fig. 5 - Floods recorded in the wadi Labiod valley at the M'chounech station

Wadi Labiod gives a torrential rain accompanied by violent floods which produce very large sediments. The comparison of the two graphs shows that the concentration is not always controlled by the importance of the flow section, it is added also other physical, lithological factors and the hydrological conditions of the flow itself.

It turns out that the liquid contribution from floods in the cold (wet) season is very significant compared to that of the dry season.

In wadi Labiod, it appears that the flow during floods is very irregular. It may be the result of the elongated shape of the valley and the nature of the lithological formations which seem relatively resistant, which gives a similar type of flood.

During the widespread flood of September 3-7, 1972, in the Aurès region, wadi Labiod evacuated 5.6 hm^3 for a peak flow of 92.5 m^3/s, or 17% of the annual total.

Generally the floods recorded in the Labiod wadi are extremely violent and appear during fall, spring and summer, producing high concentrations of fine particles.

According to Benkhaled *et alii* (2013) the month of September, have the largest number ofevents, with 20.30 % of the annual total, while the summer months (JJA) have 15.84 % and winter (DJF) 16.83%. Values exceeding 120 g/l were measured at the entrance to the reservoir of the Foum El Gherza dam during the years 2004 and 2006 (Guidoum, 2017).

It is noted that the watercourses on the southern slope of the massif mobilize very significant volumes and quantities of sediment while the northern slope offers relatively low values, this hydrological situation is interpreted by the interaction of physical and morphometric.

In general, autumn floods are the strongest, mobilizing considerable volumes of water, compared to winter floods, which remain the weakest (Bourouba, 1998). For all floods, the recession time seems very long compared to the rise time which remains relatively short.

To properly explain the general behavior of extreme flows, we are interested in the widespread floods recorded in the study area.

RESULTS AND DISCUSSIONS

Factors influencing sedimentation

Some authors explain the acceleration of dam's siltation by the conjunction of the most vulnerable lithological formations with hydrological characteristics (Orth, 1934; Remini & Bensafia, 2016), as well as for the formulas adopted, we have tried to show the role of lithology, surface area and certain hydrological factors (Table 4).

Characteristics of watersheds	SST ($t\ km^{-2}y^{-1}$)	Sd (hm^3)	Area (km^2)	P (mm)	% of soft lithological formations
Oued labiod	980	0.81	1330	380	45%
Oued Chemora	670	0.99	622	386	50%

Tab. 4 - Hydrological characteristics of the basins

Table 4 has shown that Oued Chemora watershed gave a weak erosion (670 t km^2/y) compared to the Oued labiod basin (980 t km^2/y) because the Chemora watershed occupies a considerable percentage of vulnerable lithological formations (60%).

Prediction of the evolution of siltation by empirical methods

Estimation of siltation by the formula of F. Orth (1934)

Table 5 groups together the results obtained from the siltation calculation for the dams studied for different dates.

Dam	Year	2	7	10	17	25	50
Koudiet El Medouar	C_r (hm^3)	61.98	60.70	59.95	58.22	56.31	50.74
	V_{St} (hm^3)	0.52	1.80	2.55	4.28	6.19	11.76
Foum El Gherza	C_r (hm^3)	45.39	41.59	39.47	34.92	30.37	19.62
	V_{St} (hm^3)	1.61	5.41	7.53	12.08	16.63	27.38

Tab. 5 - Estimation of siltation by Orth formula (1934)

We showed at the beginning of this work that the watering of the dams was 1950 for Foum Elgherza, currently has experienced dredging operations in addition we can mention that the first filling has been initiated in 2004 for Koudiet Medouar (ANBT, 2010).

The behavior of the siltation curves and the capacity of the dams Foum Elgherza is similar with an accelerated rhythm compared to the behavior of siltation in the Koudiet Mdouar dam which begins with a weak alluvium almost constant and increases slowly (Table 5 and Fig. 6).

Table 5 shows the decrease in the capacity of the dam and the increase in siltation as a function of time, this perfectly reflects the upward evolution of the siltation process, otherwise the useful water capacity of the reservoir is reduced by a few thousand m^3/year. Since its impoundment, the total siltation is estimated at 32.26 (hm^3) or 68.63% of the initial capacity of the dam in the year 2001 around 50 years of operation, it is completely silted in 2010, currently attests dredging operations to compensate for a third of its capacity (Tabbi *et alii*, 2012); The curves obtained shows the agreement between the observed and calculated values where the small difference arises between the observed and calculated siltation.

Orth's law has proven to be very effective and best matches the behavior of siltation in this dam.

Estimation of siltation by the Woodburn formula (1955)

Figure 6 shows that the amount of siltation calculated by the Woodburn equation for the Foum el Gherza dam gave a high value.

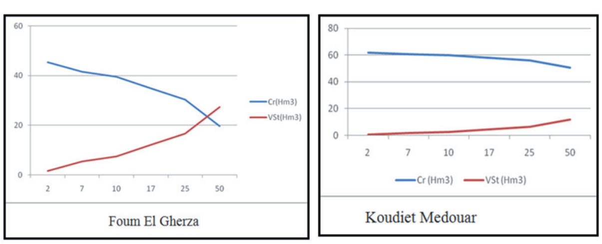

Fig. 6 - Estimation of Siltation by formula of Woodburn (1955)

The estimate of siltation in the Koudiat Mdouar dam according to the wood burn formula gives a volume of 489621.423 ton for 2 years and 1592705.68 in 10 years, however, the same formula assumes that the first two years record a cumulative silt of 1345936.49 tons while in 10 years the dam will receive 4378241 tons of silt.

When we compare the volumes obtained by this formula for Foum Elgherza dam and the volumes obtained by the bathymetric surveys of the same years (17 years and 50 years impoundment) we note that after 17 years, siltation reached is of the order of 4.3 hm^3 or 6.45 Mt where the bathymetric survey recorded during this period was 13.72 hm^3 with a difference of 9.42 hm^3.

The Woodburn formula gave low calculated volumes for the tow studied dams, compared to the values provided by the bathymetric surveys.

Results obtained by bathymetric survey measurements show that the wood burn formula gives relatively underestimated results compared to the F. Orth model.

The dams implanted on the southern slope attest to a relatively rapid and high alluvial flow (Foum El Gherza) compared to the Koudiet Mdouar dam which is located on the northern slope of the study area.

The importance of the river dynamics at the level of wadi Labiod is very active compared to wadi Timgad which attests to an erosive dynamic and relatively low alluvium. The amounts of siltation implanted into three categories:

- a high alluvial phase occupies the first ten years of operation which the siltation was rapid and less than 7.53 hm^3 for Foum El Gherza dam less than 2.55 hm^3 at Koudiat Mdouar Dam;
- a low siltation phase started from the 10^{th} year of service to 25 years where the siltation is relatively regular where the siltation records each 7 years approximately 5 hm^3 of siltation in Foum Elgherza dam and 2.2 hm^3 each 7 years for Koudiat Mdouar Dam; siltation estimated by F. Orth's equation for the same period is of the order of 16.63 hm^3 for Foum Elgherza while the Koudiet Mdouar dam only receives the volume of 6.19 hm^3.

These alluvial phases help us to form an idea of the sedimentation rate of dams in order to take this into account when constructing dams under similar conditions (Hallouche *et alii,* 2005; Bourouba, 1998). It appears very clear that the evolution of siltation is closely linked to the quantities of materials removed from each basin, and its surface area in addition the effect of hydrological parameters.

Verification of results

The Nash criterion function can be used to determine the root mean square deviation between a reference curve (Y ref (x)) and a simulated curve (Y mod (x)) which is intended to correctly model the reference curve (Gupta *et alii*, 2009). It is defined as follows (Nash *et alii*, 1970):

$$Nash=1-[(V_{Ca}-V_{obs})^2/(V_{obs}-(\bar{V}_{obs})^2]$$

V_{Ca}: calculated vase;
V_{obs}: observed Vase;
$\bar{V}_{obs}$: average of the mud for each bathymetric survey taken.

If the value of Nash=1: perfect estimate of the observed values;
if 0 <Nash value <1: estimate is better;
if Nash <0: estimate minus.

Follows the availability of many bathymetric surveys completed at the level of the Foum Elgherza dam, the comparison between the results of these surveys and the results of the ORTH formula which are very close it becomes possible and significant (Table 6).

Foum Elgherza Dam					Timgad Dam				
Year	Obs Silt (hm³)	Cal Silt (hm³)	(Ca Silt-Obs Silt)²	(Obs Silt-$\overline{\overline{Obs}}$ silt) ^2	Year	Obs silt (hm³)	Cal Silt (hm³)	(Cal Silt-Obs Silt)²	(Vobs-Vob$\overline{\overline{s}}$)²
1950	0	0	0	0	2003	0	0	0	0
1967	11.93	12 .02	0.0081	49.0140	2004	0 .5	0.52	0.0004	0.067
1975	15.07	16 .56	2.2201	14.907	2011	1.8	2.55	0.5625	1.081
1986	20.48	21.86	1.9044	2.399	Aver	0.766	1.023		
1993	22.68	24.74	4.2436	14.055	Sum	2.3	3.07	0.5629	1.1492
2001	30.1	27.64	6.0516	124.746					0.51
2009	32.26	30.14	4.4944	177 .662	2009				
Aver	**18.931**	**18.99**	18.922	741.167	Moy				
Sum	**132.52**	**132.96**	∑18.92	**741.167**	Sum				
Nash				0.974	Nash				

Tab. 6 - Calculate the Nash index (Obs: observed; Cal: calculated; Silt: siltation, Vob$\overline{\overline{s}}$: average observed siltation)

In some case there is a perfect match between the measured and calculated value. In 2004 the observed value was 0.5 hm³and the calculated value is 0.52 hm³.

CONCLUSIONS

Solid transport in Algeria is characterized by rapid filling of dam reservoirs and a considerable decrease in storage capacity and consequently the reduction in the lifespan of dams (HALLOUCHE *et alii*, 2005; REMINI *et alii*, 2015; MEDDI *et alii*, 2014).

From the present study relating to flooding and siltation in certain dams. The evolution of siltation has been increasing to reach a very advanced stage.

This development is reflected in two phases depending on the extent of the phenomenon.

A high siltation phase characterizes the first years of operation and characterized by a high flooding while a second phase is relatively long characterized by a regular siltation and a few significant floods.

The results of specific solid transports are comparable to those found in several areas in Algeria and by many researchers the values of sediment yield are varied between 450 and 980 t km²/y but in different period (KASSOUL, 2010; TEBBI, 2014; MEDDI, 2014; GUIDOUM, 2010; BOUANANI, 2004; KHANCHOUL *et alii*, 2007; TOUAIBIA, 2010;).

BALLA *et alii* (2015) have also shown that the stream in the study area is particularly affected by lateral erosion.

This erosion develops differently depending on the type of lithological formations and physical factors.

The siltation remains variable and irregular between dam and another; it takes an accelerated rate for Foum El Gherza dam.

According to BOUGAMOUZA *et alii* (2020). 1 hm³ of the silt was removed by dredging for 24 months but the value of the Nash index is 0.97, it is between 0 and 1 so the accuracy of the model is better and expresses agreement between the theoretical and measured values. Volumes of inflows that arrive after each flood can recover this sediment supply, the high alluvial behavior due to the fragility of the lithological formations and the effect of certain anthropogenic and physical factors.

The northern slope of the massif is endowed with dense and varied vegetation cover which slows down the erosive force of the rains minimizes the quantities of sediments produced, while the southern slope presents only a weak cover dominated by the scattered maquis which develop on a clearly denuded soil which makes the particles of the soil very equipped to move quickly under the flow of the floods in particular of autumn and spring (MEBARKI, 2005; HALLOUZ *et alii*, 2019). It should be noted that the Koudiet Mdouar watershed has an average plant cover reinforced by anti-erosion actions undertaken for years which reduced the average annual siltation and makes it within the limits of 0.25 hm³ (MEBARKI, 2005, TABBI, 2010) The acceleration of siltation in the Foum Elgherza dam and in the Koudiet Medouar dam is primarily due to the low vegetation cover , the intensity of erosion and the accentuation of certain morphometric and hydrological parameters.

The Woodburn estimation model, which has shown its effectiveness in certain areas, appears in this region less unnecessary and gives underestimated results.

It is clear that F. ORTH's model gives results close and comparable to those found by bathymetric surveys, which qualifies this model to be applicable in similar climatic, physical and lithological conditions and to put in the hands of engineers and decision-makers an effective alluvial forecasting tool that rapidly replenishes reservoirs and considerably reduces the lifespan of dams.

We could say that we tried to better explain the main goal of this study which was the relationship between floods and dam siltation in two adjacent basins with different hydrological, lithological and climatic characteristics.

We note that there is a strong relationship between dam siltation and floods that carry largest amount of sediment, especially floods during wet periods such as autumn and spring.

Basins studied suffer from the degradation of vegetation under the effect of fires and drought, which accelerates the action of violent floods and the sensitivity of the soil to erosion and the rapid mobilization of sediments towards the dams.

Reservoirs need great importance for water storage, for agricultural, and they contribute to flood risk mitigation (CORTI *et alii*, 2023).

Some techniques give good results in the fight against erosion water and siltation, we can cite:

- soil conservation as a means of minimizing the penetration of solid materials into a reservoir, two methods of soil conservation are used to curb erosion by the establishment of: planting of crops along the contour lines and fixing the banks of the watercourse;

- the densification of reforestation, particularly in the upstream part of Timgad, will fix the formations of vulnerable Mio-Pliocene clays and construction of upstream settling dams;
- discharging and scouring are the most important methods of reservoir scouring, which mainly use the impacts of headwater scouring and on-way scouring to recover the capacities of reservoirs (Hu *et alii*, 2018; Chamoun *et alii*, 2016);
- underwater dredging: this method is applicable to dredge reservoirs with water storage throughout the year;
- withdrawal of density currents (drawing off): a practical method which consists in evacuating the sediments drained by the density currents on the bottom of the reservoir by using drain slits (drain valves or bottom valve) from the dam; as soon as the roof of the sludge reaches the threshold of the valves, the turbid layer is above, and its withdrawal becomes easier (Benblidia *et alii*, 2001; Remini *et alii*,1997).

The installation of settling basins is among the most effective choices which can retain sediments and slow down the effects of flooding, particularly in the upstream and middle part of the wadi Labiod dam.

For wadi Labiod watershed it turns out that the mechanical protection will be more effective than the biological protection which remains the best solution for the wadi Timgad basin to fight against erosion and the slowdown floods.

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