



Hydrological Flows and Flood Protection: Case Study of the Mexa Dam (Mafragh River Basin, North-East Algeria)

Samia Affoun Ikhlef, Azeddine Mebarki and Mohamed Taabni

Abstract

The exploitation in 2003 of the Mexa dam on the wadi Kebir-East (capacity 30.27 hm³/year) is a major element of the integrated water management objective of the Mafragh, a transboundary basin of the well-watered region of North-East Algeria. This contribution aims to analyze the hydrological inputs to the dam with the regulation balance, the management, and the discharges of the excess volumes during flood periods. Since its impoundment, the Mexa dam has been confronted with important and irregular hydrological inputs. It is also the receptacle of the releases of the two dams, Bougous and Barbara, located upstream. In rainy years, the discharges (spillway and bottom drain) from Mexa can be very high (especially from December to April): 621 hm³ in 2004/2005 and 613 hm³ in 2011/2012 (i.e., 163% of the average interannual inflow). They are carried out for flood control and the structure's safety but are a factor in the aggravation of floods on houses and agricultural lands downstream. Moreover, the period of flood discharges can extend over several months (159 successive days following the floods observed in December 2003–January 2004 and 143 days during the February–March 2012 floods with the release of a volume of 562 hm³). Therefore, questions of effective flood protection and integrated management of mobilized water resources on a basin-wide basis remain.

Keywords

Hydrology · Dam · Inflows · Flood management · Mafragh river basin · Eastern Algeria

1 Introduction

Securing the water supply for the population and mitigating the adverse effects of flooding are central objectives in integrated water management and planning efforts (Negm et al., 2020). This holds true for the Mafragh basin, situated in the abundantly watered region in the extreme northeast of Algeria. The exploitation 2003 of the Mexa dam on wadi Kebir-East was a response to this goal. However, the excess volumes evacuated by the dam to reduce floods and ensure the safety of the hydraulic structure are, in some cases, a chief factor of flood amplification in the plain of El Tarf-Annaba downstream. In the latter, important agglomerations and vast agricultural lands are present.

2 Materials and Methods

2.1 Situation and a Brief History

The Mexa dam (capacity: 30.27 hm³; regulable input: 47 hm³ per year) is erected downstream of the confluence of three rivers draining the Algerian–Tunisian transboundary basin of the Kebir-East. Their confluence is located 2 km South of the earthen dam, before the short and steep gorges through which the Kebir-East crosses the last section of the Numidic chain (Marre, 1987).

This basin covers an area of 651 km² and 328.5 km². It is located in Tunisian territory. The two tributaries, Oued Bougous and Oued Barbara, are equipped with dams whose releases end in the Mexa reservoir (Fig. 1).

Programmed in 1982, with a coast of the normal reservoir of 85 m, a capacity of 295 hm³, and a regulatable

S. A. Ikhlef (✉)

Université Badji Mokhtar Annaba, Sidi Amar, Algeria
e-mail: samia.affoun@univ-annaba.dz

S. A. Ikhlef · A. Mebarki

Laboratoire LASTERNE, Université Frères Mentouri Constantine, Constantine, Algeria

M. Taabni

Laboratoire RURALITES, Université de Poitiers, Poitiers, Algeria
e-mail: mohamed.taabni@univ-poitiers.fr

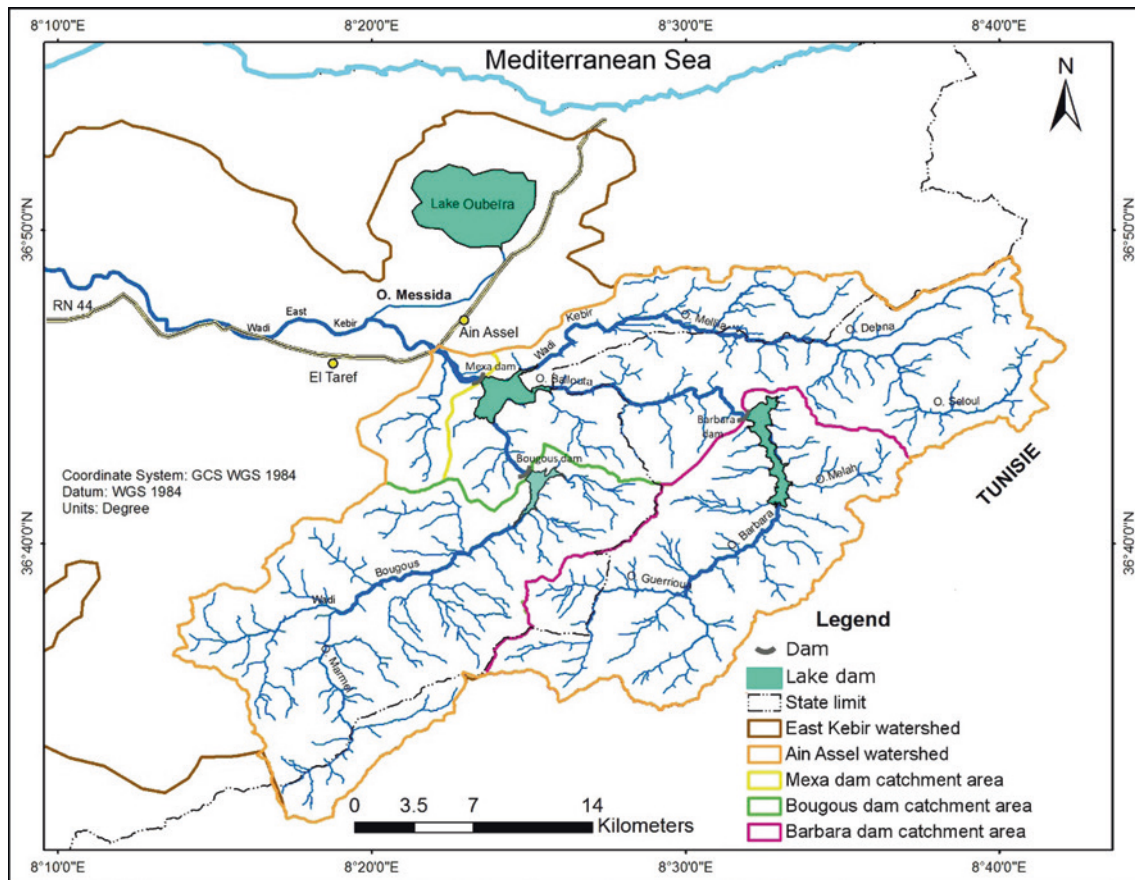


Fig. 1 Location of the Mexa, Bougous, and Barbara dams watersheds in the East Kébir watershed

volume of 175 hm³/year, the Mexa project was revised downwards (flooding risk of 180 ha of land in Tunisian territory) (MRE and ANBT, 2011). Its coast was reduced to 58 m and its regulable volume to 47 hm³/year. The compensation of the initial regulated volume is partially provided by the Bougous dam, impounded in 2011 (capacity: 65.2 hm³; regulable volume: 24.37 hm³/year) (ANBT, 2017). The Tunisian Barbara Dam (capacity: 74.2 hm³, regulable volume: 80 hm³) aims to contribute to economic and social development in rural areas of Tunisia (ONAGRI, 2019).

2.2 The Watershed and Hydrology of Wadi Kébir-East

The East Kébir watershed is characterized by moderate relief (the dominant altitude range over an area of 601 km² is <100 m). The mountainous massifs at higher than 600 m are located in the South of the watershed. They represent only 15% of the total area. They are essentially lands of the upper Eocene–Oligocene (clays and sandstones called Numidian). On the slopes, formations of marl-clay soils are observed. The alluvial deposits occupy the surfaces of the

basins. The vegetation cover is still vital despite the clearing for cultures.

The watershed is subject to the humid Mediterranean climate with an interannual average rainfall of 835.32 mm/year (Ain Assel station, period 1968/69–2019/2020). According to the IDF curves, the maximum daily rainfall with a return period of 100 years can reach 163 mm, with a maximum hourly intensity of 55.5 mm (ANRH, 2015). As a result, the annual water flow is 311 mm at the Ain Assel station (observation series from 1947/48 to 2002/03), with an interannual contribution of 211 hm³. Over this 51-year series, 88% of the annual maximum instantaneous flows are recorded during the rainy period from December to April.

2.3 Mexa Dam Water Balance Data

Data on daily terms of the Mexa dam balance (inflows–outflows–reserves) are provided by ANBT (National Agency for Dams and Transfers), covering 17 years (September 2003 to August 2020) (Fig. 2). The average interannual inflow measured at the dam is 380.12 hm³ (ANBT, 2020). It is significantly higher than the hydrometric station's inflow

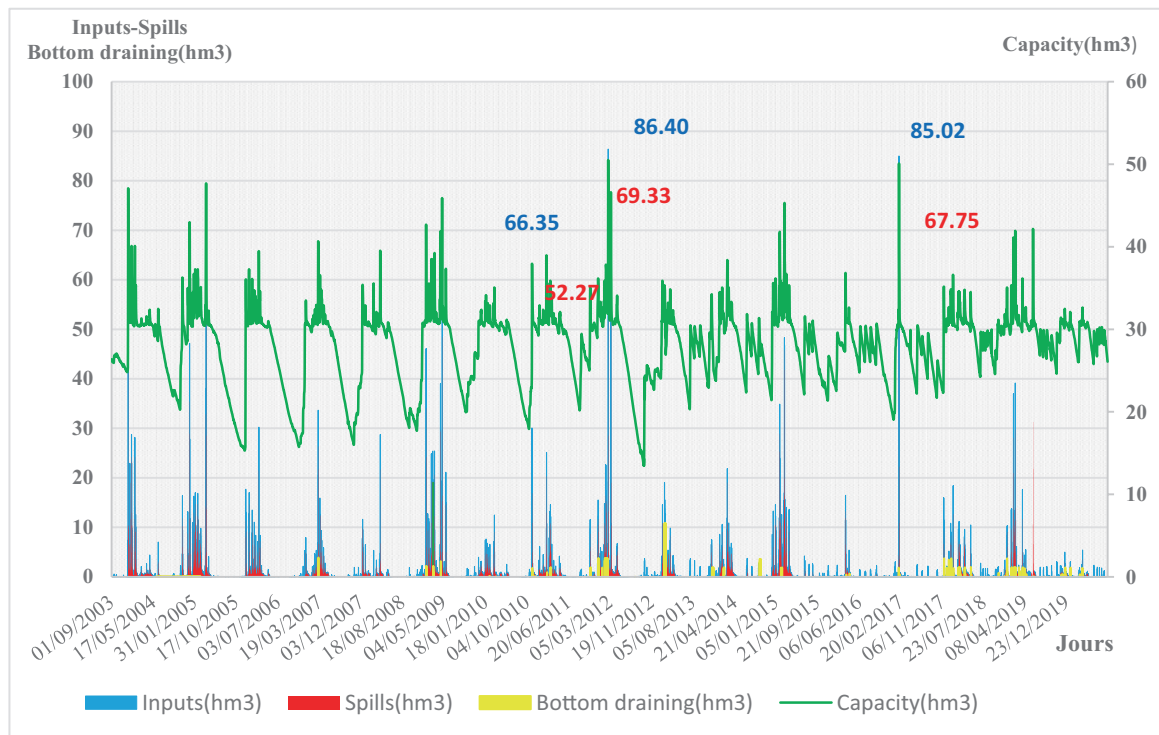


Fig. 2 Daily hydrograph of inflow, flood spill, and capacity (reserve) of Mexa dam (observation period 2003–2020)

before constructing the dams: Mexa, Bougous, and Barbara in Tunisia. Moreover, according to the series of maximum daily inflows, remarkable peaks of flows are observed (around $1100 \text{ m}^3/\text{s}$ during the exceptional flood of February 2012) (ANBT, 2012).

3 Results

3.1 Reservoir Water Balance

According to the 17-year observation series of Mexa dam operation, a maximum inflow of 686.94 and 687 hm^3 was recorded during the rainy years of 2004/2005 and 2011/2012, respectively, for annual rainfall of 1150 and 1120 mm/year , respectively. On the other hand, the lowest input ($120 \text{ hm}^3/\text{year}$) was recorded during the dry year 2015/2016. As a result, the year-end capacity varies between 20 and $29 \text{ hm}^3/\text{year}$, i.e., a filling rate that varies between 67 and 96% , except the year 2011/2012, which recorded a low filling rate (53%).

The total volume discharged by the flood spillway varies from 67 hm^3 (the dry year of 2015/2016) to 659.3 and 590.98 hm^3 (wet years of 2004/2005 and 2011/2012). The

flood discharges can extend over several months (159 successive days following the floods observed in December 2003–January 2004 and 143 days during the floods observed in February and March 2012).

3.2 Daily Inflows and Spills

The daily balance of inflows and outflows in relation to variations in the dam's reserve (capacity) is shown in Fig. 2 for the period from September 1, 2003, to August 31, 2020. The dam was marked by 30 floods with an inflow greater than $20 \text{ hm}^3/\text{day}$. Regarding the exceptional flood of February 22–23, 2012, a maximum daily influx of 86.40 hm^3 (or 27.6% of the monthly total for February) was recorded at Mexa. As a result, the maximum daily discharge reached 69.33 hm^3 . The dam management agency reproduced the hourly hydrograph of spillway flows measured over 66 h. According to the ANBT report (2012), the peak spillway discharge rose on February 22 at 11:00 p.m. to $1094 \text{ m}^3/\text{s}$, corresponding to an elevation of 56.50 m , equivalent to a 4.5 m overflow, causing damage to the spillway. A second flood wave was recorded at Mexa dam on March 11, 2012. The maximum daily inflow reached 66.34 hm^3 , i.e., a daily discharge of $767.8 \text{ m}^3/\text{s}$.

3.3 Flooding and Damage in the Downstream Plain

Floods with harmful consequences manifest the abundance of surface runoff in the Mafragh watershed. For 25 days, from February 20 to March 15, the plain of El Tarf was the receptacle of runoff and excess volumes (242 hm³) discharged in the emergency by the Mexa dam. In addition, 175 hm³ of water was evacuated by the Cheffia dam, a water regulation structure for the Bounamoussa Wadi. Of the 24 rural districts in the region, 15 were affected by flooding, 9 of which were at high risk (Affoun et al., 2019). Following the floods of February 22 and 23, 2012, the flooded area in urban areas (Ain Assel, El Tarf, Bird Lake, Sebaa, Sidi Kaci, etc.) were estimated at 40 km². Several settlements were victims of isolation, particularly the houses near the Wadis Bouroumana and Kébir East. According to the report on civil protection, 350 interventions had been carried out in 56 neighborhoods across 15 municipalities (DPC, 2012). The economic cost of flooding is reflected in redevelopment operations at the level of several sectors and compensation to farmers throughout the wilaya (Affoun et al., 2019).

4 Discussion

The vulnerability of the flood-prone sectors of the El Tarf-Annaba plain is increasing with the extension of urbanized areas of towns that are exposed to floods, accentuated by the release of dams. In rural areas, these floods have caused losses of agricultural production (21,000 ha of farmland were submerged in water) and destruction of hydro-agricultural infrastructure. The hydro-agricultural development of the El Tarf plain carried out in 2011 is a project that also aimed to limit the extent of flooding by regulating the watercourses and draining the flood-prone land for their intensive development (9,118 ha) (MRE and ANBT, 2011). The reference flood retained in the realization of the project is of a twenty-year frequency for a project height of 10.37 m (height of the dykes) with 60 cm of safety level for the highest waters (PHE). Significant damage was recorded on the dikes and protection structures of the plain development, following the floods of 2012 and February 2015. They showed that the reference flood had probably been underestimated for effectively protecting agricultural lands.

5 Conclusion

During the exceptional floods of 2012, the plain of El Tarf, especially in its eastern part, was the receptacle of the cumulative flows and excess volumes (242 hm³)

discharged in the emergency by the dam of Mexa. The vulnerability of the floodplain is accentuated by an extension linked to new urban perimeters of settlements, which requires urban planning that takes into account the issues related to flooding. Protective measures for the Kebir-East Valley agricultural land showed their limits (damage generated by the floods of 2012 and February 2015). The issue of undersizing the Mexa dam arises, which requires adopting a water flow management strategy by optimizing the use of the mobilized water resource. The interconnection of existing dams (Mexa, Cheffia, and Bougous) and those under construction (Boukhroufa) and planned (Boulathane dam, BounamoussaII dam as well as the water intake on wadi Kebir-East) will contribute to a broad control of surface water of the Mafragh basin but also a reduction of the flood hazard for the territories downstream (ANBT, 2017; DWR, 2015). Transferring to the wilayas of Souk Ahras and Guelma part of the lost volumes during each intense rainy episode would be an economically, socially, and environmentally beneficial solution.

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