Study of the impact of drought on the runoff system and the dam on Oued Za using romote sensing techniques (Eastern Morocco)

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Abstract. The irregularity of precipitation that most Moroccan territories receive is mainly due to the association of precipitation with the atmospheric system in general. This phenomenon has an obvious impact, particularly in semi-arid areas, which suffer from scarcity of water resources and low precipitation rates. In turn, the Oued El Hay basin (northern margins of the highlands) is characterized by aridity resulting from its difficult climatic conditions, since climatic elements have an important and decisive role in the periodic and more severe occurrence of droughts, due to their seasonal variations throughout the year. This is directly reflected in the general water supply, whether surface runoff, which remains low in the region, or groundwater, which is directly affected by prevailing climatic conditions. The fluctuation and lack of precipitation is reflected in the water inputs that feed the groundwater, given the excessive exploitation to which the water is exposed to meet the growing needs of the region. Given the relationship between surface runoff and the volume of water supplies mobilized, the frequency of droughts has a significant impact on the volume and supply of water mobilized by dams. At the basin level, a significant drop in the volume of inflows was recorded at the dam on Oued Za. The maximum recorded in 2004/2005 did not exceed 46 million m³. This article aims to highlight the impact of drought on the surface runoff system of Oued El Hay, to study the evolution of the volume of water from the dam on Oued Za based on data recorded between 1978/79 and 2020/21, and to monitor the volume of water mobilized using remote sensing techniques.

Keywords: Runoff, drought, remote sensing, Oued Za dam, eastern Morocco.

1. Introduction

The dam on Oued Za is situated on Oued Za, a principal tributary of the Moulouya River. It was commissioned in February 1999. The primary objective is to secure the irrigation water supply for the perimeters of Taourirt and the lower Moulouya, control floods at the Mohammed V-Mechraa Hammadi hydraulic complex, and protect these structures from siltation.

The reservoir of this dam is normally operated between the level of 642.5mNGM, the minimum operating level corresponding to the threshold of the agricultural intake, and the level of 675mNGM, corresponding to the normal reservoir level. The free spillway threshold is at 689NGM.

A flood control volume of 150Mm3 is reserved for flood management. Initially, the volume corresponding to the useful capacity of the reservoir was 125Mm3, but it has currently decreased to 95Mm3 (according to the 2013 bathymetric survey) due to the siltation of the reservoir. The average siltation rate of the dam is approximately 2.14Mm3/year. The dam is equipped with a free overflow spillway with a spill length of 60m set at an elevation of 689.00mNGM. It is subdivided into 4 bays of 15m each, separated by 1.5m wide piers.

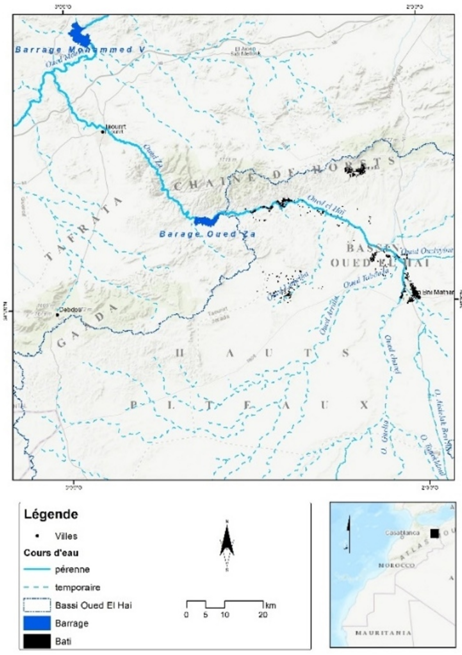

Fig. 1. Study area situation

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2. Research Material and Methodology

This study, aimed at monitoring the volume of surface water stored in the Oued Za dam, cannot be conducted solely using remote sensing techniques, as satellite imagery analysis only allows for determining the surface area of the water body stored in the dam, not the volume.

For clarity, our study is conducted in two stages. In the first, we rely on the processing of measurement series recorded at the Oued Za hydrological station, which present the annual averages between 1998/99 and 2020/21.

The second stage involves analyzing Landsat 7 satellite images for the years 2000, 2010, and 2020. This allows us to highlight the evolution over a period of approximately 30 years since the construction of the hydraulic structure. Two methods are used for this purpose:

- **The calculation of the Water Stress Index**: The Normalized Difference Water Index (NDWI) was proposed by McFeeters in 1996 (McFEETERS S. K. 1996). Today, it is primarily used to detect and monitor small changes in water content in water basins. Using the advantages of NIR (near-infrared) and GREEN (visible green), the Normalized Difference Water Index (NDWI) improves the detection of water basins in satellite images. However, this index is sensitive to built structures, which can lead to an overestimation of water basins. It is calculated based on the GREEN-NIR combination (visible green and near-infrared) by the following equation: NDWI = (GREEN - NIR) / (GREEN + NIR). For Landsat 7 data (8 bands): NDWI = (Band 2 - Band 4) / (Band 2 + Band 4) Visible green maximizes the reflection capacity of the water surface. Near-infrared maximizes the high reflection capacity of terrestrial vegetation and soil elements while minimizing the low reflection capacity of water basins. The results of the NDWI equation resolution for the NDWI index are water basins and negative (or zero) values for soil and terrestrial vegetation.
- **Supervised Classification:** This method is based on the classification of satellite images using image processing software (ERDAS). In geography, one frequent goal of remote sensing is to produce a land use classification of a region from satellite images. In most cases, we use a supervised classification procedure to control the number and nature of the classes that will be produced (Paul Passy 2023). Like any supervised classification, it is necessary to delineate training polygons corresponding to the desired classes. For our case, we have three classes. We have digitized three representative polygons: surface water, soil, and vegetation formations (agriculture, forest, etc.) for each satellite image of the three chosen periods.

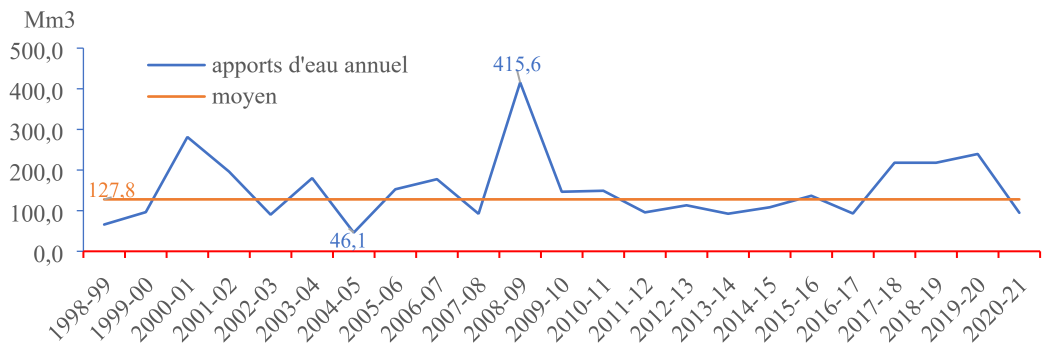
3. Results and Discussions

1. Periodic drought affects the volume of water stored in the dam

In general, the response of surface water runoff to precipitation variations is relatively rapid (El Mehdad 2003), especially since changes in runoff flow follow the same pattern as changes in rainfall inputs. The low flow of Oued El Hay, which is relatively permanent and oscillates between less than 2 liters/second at the Ain Beni Mathar station and about 35 liters/second at Gafait on average (1994/95 and 12/2011), reflects a low precipitation rate that does not exceed 220 mm and 190 mm respectively at these two stations. Given the relationship between surface runoff and mobilized rainwater volume, the frequency of droughts has a significant impact on the mobilized water volume by dams. In the Oued El Hay basin in the northern high plateaus, a significant decrease in water inputs has been recorded at the Oued Za dam.

The variations recorded in water inputs at the dam had obvious effects due to the frequency and duration of drought periods, as the dam received significant inputs amounting to 4156 million m^3 during the 2008/2009 year with an estimated rainfall rate of about 385 mm, whereas these inputs did not exceed a total of 46 million m^3 during the 2004/2005 year, considered a dry year, with average rainfall recorded at the Oued Za station not exceeding 105 mm.

Most studies confirm that the period between 2018/19 and 2021/2022 represents an exceptionally dry period that affected the entire national territory, during which rainfall totals reached minimal levels. This was reflected in the water inputs received, which did not exceed 174 billion m^3, exceeding the lowest volume of inputs received between 1991 and 1995, which was about 176 billion m^3. Thus, this period recorded a significant decrease in inputs of 83% during the 2021/22 year compared to the annual national average, which received the lowest volume of water during this period. It is the year that recorded the lowest volume of water with decreases of 54% in 2018, 71% in 2019, and 59% in 2020 during the other three years (Ministry of Equipment and Water 2023).



Source: Moulouya Basin Agency in Oujda

Fig 2: Annual average water inputs at the Oued Za dam between 1970/71 and 2020/21

Overall, the volume of water arriving at the dam is irregular during the studied period between 1998/99 and 2020/21 (see Figure 2) with an average not exceeding 1278 million m³.

The percentage decrease between the highest and lowest recorded values in the mobilized water inputs by the dam was estimated at about 3695 million m³. This decrease is due to several reasons, whether related to the decrease in water inputs in the basin and the frequency of droughts or related to the increase in water demand, knowing that the dam water is also used for irrigation (about 1 m³/s).

However, what draws attention is the filling rate, which did not exceed 59% as of December 31, 2020, possibly related to the high siltation rate averaging 2 million m³/year according to studies conducted by the Moulouya Basin Agency (ABHM 2019). It should be noted that during the period 1999 – 2013 (see Table 1), the siltation rate significantly increased at the Oued Za dam, reaching a recorded maximum of about 18 million m³ in 2013, with siltation occupying up to 67% of the dam's capacity.

Table 1. Evolution of siltation at Oued Za dam (1999-2013)

Years	1999	2001	2002	2004	2008	2013
Siltation (Mm³)	0	10,3	10,9	9,7	2,2	18

Source: Moulouya Basin Agency in Oujda

2. Study and Monitoring of the Water Surface Area Mobilized in the Oued Za Dam

2.1 NDWI Method

The results of the NDWI index show a clear difference in the water surface area mobilized by the Oued Za dam, applied to satellite images of the same month over a 20-year period between 2000 and 2020. The results showed the importance of the water surface area in 2000, which extended over an area of about 10 km² with a volume amounting to 2813 million m³, while this volume decreased to 14904 million m³ in 2010, a decrease of about 1322 million m³ (47%), covering an estimated area of about 7 km², reducing the area by about 3 km².

As for the year 2020, the mobilized water surface area represented only about 5 km², with a water volume that did not exceed 949 million m³, the dam having lost about 542 million m³, or about 366% compared to the year 2010 (see Table 2).

Table 2. Evolution of water inputs and lost volume (Mm³) at the Oued Za dam between 2000/2001 and 2020/2021

Periods	**Initial Volume**	**Evolution**		**Evolution of Water Surface (NDWI) in km²**
		Lost volume	**%**	
2000/2001 - 2020/2021	281,3	186,4	66,3	5
2000/2001 - 2010/2011	149,04	132,2	47,0	3
2010/2011 - 2020/2021	94,9	54,2	36,3	2

Source: Moulouya Basin Agency in Oujda

The results of the NDWI index highlighted the reduction of the water surface area covered by the dam. This is clearly consistent with the decline in its surface area since the results confirm a decrease in the surface area during the period between 2000 and 2020 (see Figures 3-6) by about 5 km², which was accompanied by a reduction in surface area limited to about 1864 million m³ (with a rate of 62 million m³/year), a decrease of 663%. This can be explained by the nature of the studied years between wet and dry years, confirmed by the recorded rainfall volumes at the Oued Za station, indicating that the total in 2000 was 2102 mm, while this rate decreased to 1664 mm in 2010. Studies confirm that rainfall in the Moulouya basin decreased by about 20% between 1931 and 2016 (ABHM 2019). The drought wave the region has experienced since 2019 is reflected in the decrease in water inputs, estimated to February 2024 at about 69%. The volume of water inputs entering the Oued Za dam totaled 66 Mm³. The deficit this year reached about 28%.

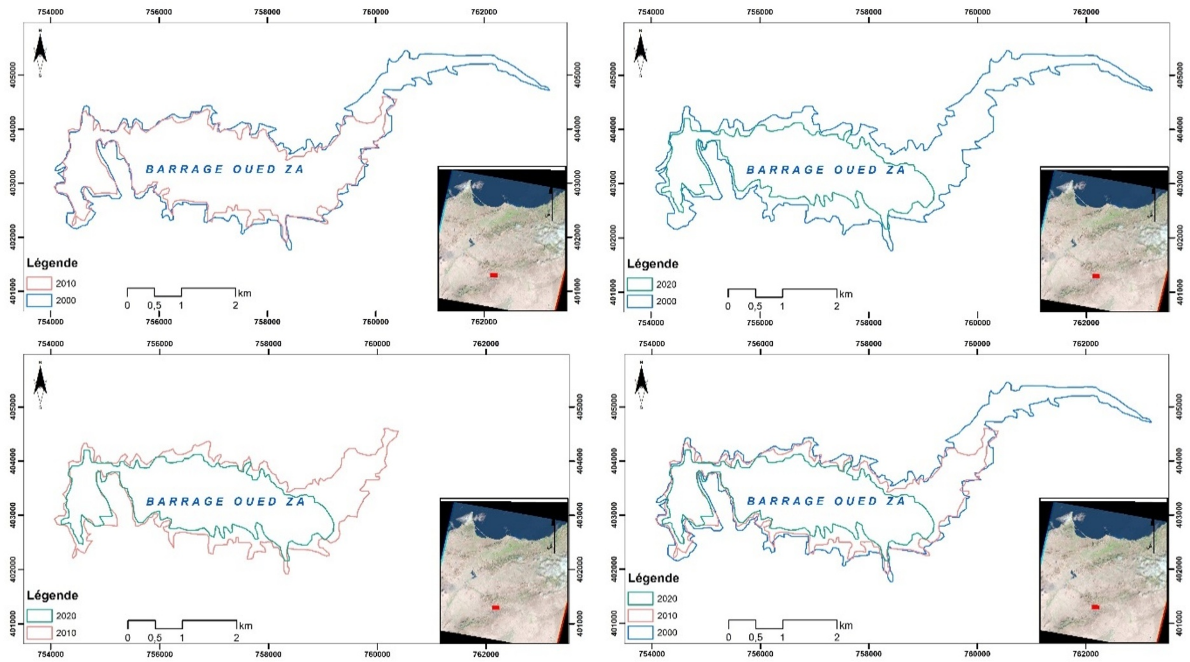


Fig. 3-6. Application of the NDWI to monitor the evolution of the water surface area of the Oued Za dam between 2000 and 2020

2.2 Supervised Classification Method

This method relies on sampling the satellite image to guide the classification process. Through this process, the extent of the dam's volume decline becomes clear. The results of this method confirm the reduction in the water surface area mobilized in the dam.

This has previously been proven, whether through recorded data or the NDWI method. However, this classification method remains relative compared to the first method as the error rate remains high in classifying different surface aspects in the image. The types overlap, and it is sometimes difficult to distinguish them due to the poor quality of the satellite images used or the presence of distortions. The validity of the results of this method essentially depends on good knowledge of the studied terrain, the quality of the images, and the accuracy of the samples used for classification. The documents below present the obtained results and show the reduction of the water-filled area by the dam, as indicated by the blue color representing the water surface in 2000, 2010, and 2020 (see Figures 7-8 and 9).

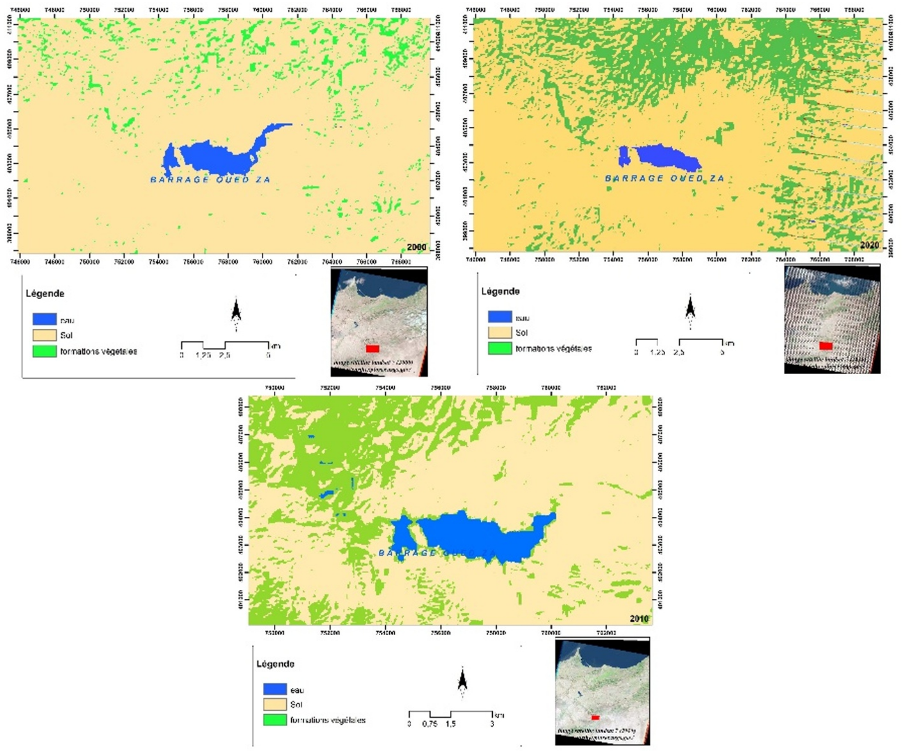


Fig. 7-8 and 9. Results of the supervised classification of satellite images 2000, 2010, and 2020

4.Conclusion

The current state of the Oued Za dam and other dams in the Moulouya basin confirms a clear decrease in dam capacity, primarily related to the periodic drought experienced by the region. This drought has led to a decrease in the volume of water inputs the basin receives in general, given the growing water needs of the region and the high demand for this resource, whether to cover irrigation water needs or to meet the population's drinking water needs. This necessitates accelerating the adoption of measures aimed at reducing water waste and mismanagement.

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Author contribution
All authors reviewed and approved the final version of the manuscript. M. Ghzal conceptualized and designed the study, including data collection and processing. A. Sbai contributed by verifying the obtained results, correcting the text, and translating it, while O. Mouadili participated in the cartographic work using Geographic Information Systems (GIS) and remote sensing.
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Consent for publication
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Competing interests
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