The dam reservoir of Bin El Ouidane (azilal, morocco) face to climate change

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Abstract— Morocco opted earlier, for a dynamic and anticipative dam's policy. This policy has helped to face the water scarcity and hydro-climatic irregularity related to Climate Change (CC). In the aim of preparing the managers of these dams to a new management mode, that considers the potential impacts of CC, we've tried to analyse the climatic and hydrologic behaviour in the dam of Bin El Ouidane (Azillal, Morocco), and the water management practiced during the past decades and to deduct the trends that might help in future projections.The climate behaviour resulting follows the global trends described in the IPCC reports : A continue accelerated climate warming, associated to high evaporation, a global decrease of rainfall, characterized by an alternation of dry and wet periods and even sometimes very wet periods, as it is the case in Morocco since year. The reservoir water management has followed this hydro-climatic cycle. Assignments of water for irrigation depend on the amount of rainfall in each year. This water allocation has increased in general, considering the augmentation of water demand required for the development of the Tadla-Azilal.In addition, this analysis helped to show how the hydro-climatic context had evolved around this dam, with water supplies diminution in the period after 1975/76, compared to the period before. It is important to mention that between these two periods, a change was also identified in terms of the intra-annual evolution of water supplies. This can be explained in part by a change in the hydrologic behaviour upstream the dam, which loose progressively its pluvio-nival regime, to a regime much more pluvial. Concerning the water management in this reservoir, it was made reactively, and might be much more efficient, if the CC has not started to destabilize the climate of the region and its hydrologic system.

Index Terms— Bin El Ouidane, climate change, dam, management.

1 Introduction

THE Bin El Ouidane reservoir dam was constructed in 1953. It is one of the first big dams constructed in Morocco, and which satisfy since, various demands: drinking water, irrigation and hydroelectricity. These reservoirs represent one of the key elements of the water policy, adopted by Morocco since the sixties. A policy, which particularly allowed to face up water scarcity and the climate variability, which characterizes this region.

The CC is a reality today, and that, in any case, will continue for coming decades with its various impacts, notably on the water sector. This CC should, according to the predictions of IPCC [IPCC, 2013], impact the air temperatures, rainfall, evaporation and the water demand. The region of Maghreb seems to be particularly exposed to this risk.

In order to prepare managers of these dams to a new mode of reservoir management, considering the CC impacts expected, and to offer approaches and appropriate methods of management, it is important to analyze hydro climatic behavior around these dams during last century, and to deduct consistent conclusions. This is what has been achieved, and which is the subject of this publication for the case of Bin El Ouidane dam (Azilal-Morocco). The objective of this research is to analyze the climate and hydrological behavior around this reservoir, and the water management practiced during last decades (1939-2013), and to identify trends that can help for future adaptation.

This analysis was based on complete data series of water supplies to the reservoir (1939-2013), and limited ones for the temperature of air (1989-2013) and for rainfall / evaporation (1976-2013). These data were measured (Fig.1):

- In The Bin El Ouidane dam for the management variables, the rate of evaporation and water supplies;
- In the gauge of Tilouguite upstream of the dam for the temperature, rainfall and evaporation rate;
- In the gauge of Ait Ouchène upstream also, for rainfall.

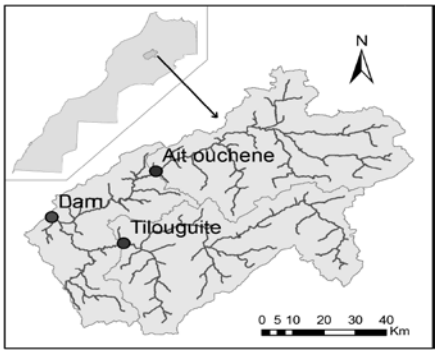

Fig. 1. Situation map of the Bin El Ouidane dam watershed (Azilal-Morocco).

2 Evolution of Hydro-climatic Variables

2.1 Air Temperature

It is a parameter with a big importance for the reservoir management. It will particularly condition the evaporation of waters from the reservoir, the quality of these waters and the wa-

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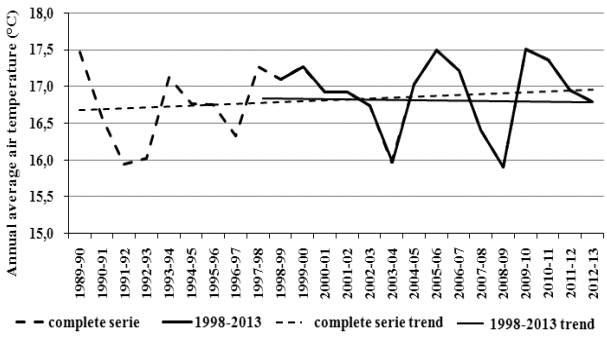
ter demands requested by each user. The Fig.2, shows a significant increase of the annual average air temperature in the region during the period 1989/90-2012/13 (around 0.4°C in about twenty years!). We also notice a stabilization, or even a decrease of the annual average air temperature during 1998/99 - 2012/13, as it was the case at global level. This tendency to warming for the entire period, and the stabilization during the 1999-2013, are in accordance with the tendencies reported in the 5th Assessment Report (AR5) of the IPCC [IPCC, 2013].



2.2 Rainfall in the Region

The rainfall data used in this analysis are limited to the period 1976/77 - 2013/14 (Fig.3). During this period, we can't distinguish a significant reduction, as described at the AR5 for the North African region. This can be linked to local climatic conditions. However, we note that the study period can be divided into two parts:

- The first one between 1976/77 and 1994/95, rather dries with some humid peaks limited in terms of duration and intensity. This period reflects the long and severe droughts experienced by Morocco during the eighties [Stour and Agoumi 2008].
- The second period starts in 1995/96 until 2013/14, characterized by high humidity intercalated by dry years and generally less intense.

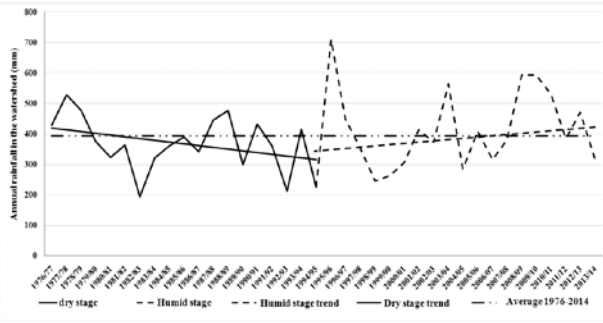
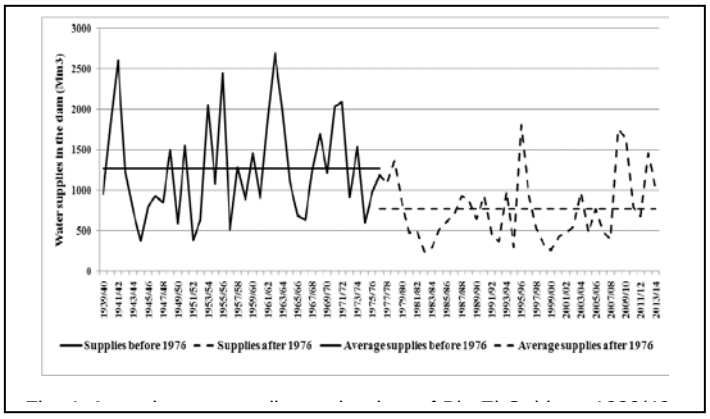


Fig. 3. The annual average rainfall at the Tilouguite and Ait Ouchène

2.3 Water Supplies in the Reservoir

Water supplies recorded in this dam from 1939/40 to 2012/13 (Fig.4) show a net reduction of the average of water supplies between the period 1939/40 - 1975/76 and the period 1976/77 - 2012/13. This last period was much drier hydrologically, with an average of annual supplies of 764 Mm3, against 1265 Mm3 for 1939/40 - 1975/76, that is a diminution of almost 40 %. This confirms the same tendency noticed at the level of the Mediterranean region mentioned in the AR5 [IPCC, 2013].



It is important to note that between these two periods, before and after 1976, a change was also found at the level of the intra annual evolution of supplies. The Fig.5 shows not only monthly water supplies systematically more reduced after 1976, but also:

- A delay, of at least a month, in the first significant supplies of the winter.
- A gap of the water supplies peak of 1 month: from April to March.
- A reduction of the rainfall period length: from December to June (7 months) before 1976, and from January to May (5 months) after 1976.

This can be explained partly by a change in the hydrologic behaviour of the Bin El Ouidane dam watershed, which loses progressively its pluvio-nival character, towards mostly pluvial character, because of the diminution of the solid rainfall (snows) in relation with global warming. This change confirms the conclusions of the IPCC last report, concerning the reduction of the surface of the snow cover in high altitude [IPCC, 2013], the high Atlas in our case. In fact, this point had been proved implicitly by [Elkhalki, 2015], during the modelling of Bin El Ouidane dam watershed. He concluded that the hydrologic models, integrating a snow component, lead to much less performance in calibration and validation than those incorporating only the liquid phase of precipitation.

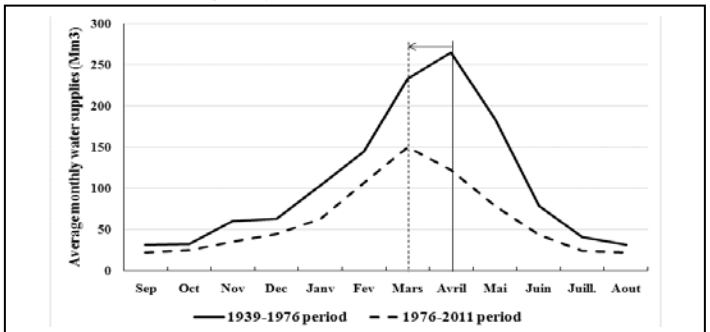


Fig. 5. Average monthly supplies in Mm3 to the dam of Bin El Ouidane for the period 1939/40 - 1975/76 and 1976/77 - 2010/11.

In addition, a particular analysis of water supplies recorded on 1976/77 - 2013/14, highlights two distinct phases: The first one which ends by 1995, is characterized by a trend to decrease caused by the years of droughts experienced by Moroc-

co during this period [Stour and Agoumi, 2008]. The second begins after 1995, and shows a trend rather to increase of supplies through to the increase of the rainfall (Fig.6).

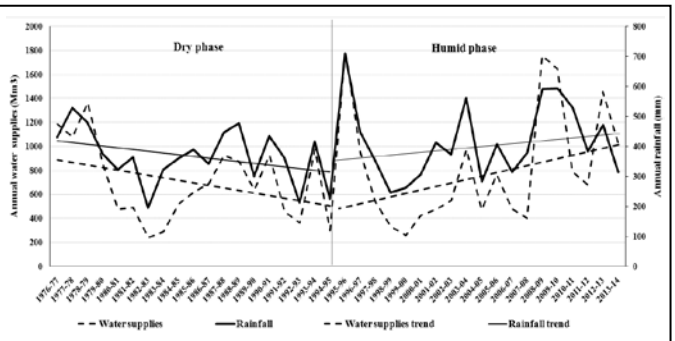


Fig. 6. Water supplies to the Bin El Ouidane dam and the annual average rainfall at the Tilouguite and Ait Ouchène gauges 1976/77 - 2013/14.

2.4 Evaporation Rate in the Dam Watershed

The analysis shows an increase of the evaporation rate during the period (1976/77 - 2012/13). This increase is explained by the air temperature augmentation. This is reflected in the measures taken to Tilouguite station (1985/86 - 2012/13), and also in the calculations made for the dam reservoir (1976/77 - 2005/06) (Fig.7). This trend was reported in the AR5 for the North African region [IPCC, 2013].

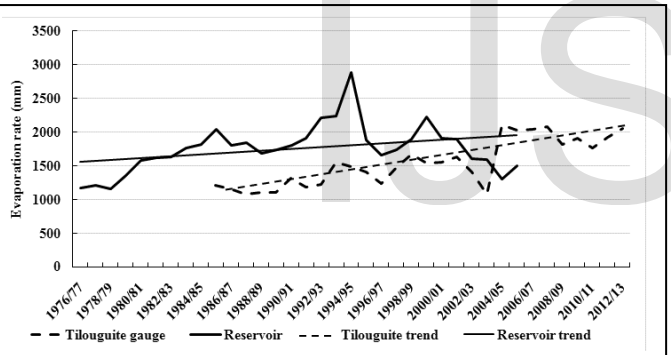


Fig. 7. Annual evaporation rate in mm measured at the Tilouguite gauge 1985 / 86 - 2012/13 and calculated in reservoir of Bin El Ouidane dam 1976/77 - 2005/06.

3 Evolution of the Management Variables

3.1 Volume of the Water Evaporated from the Reservoir

The annual volume of water evaporated from the reservoir shows a trend of increase during the period 1976-2013. This is due, in part, to the increase of the air temperature and the evaporation rate mentioned above, and on the other hand, to the increase of the water surface area in the reservoir in flood periods, which also conditions significantly the evaporated volume (Fig.8).

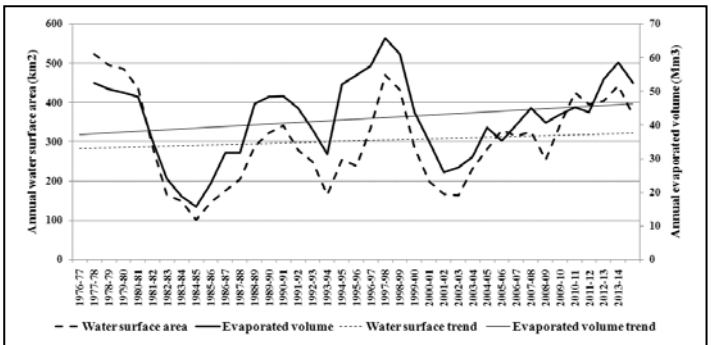


Fig. 8. The annual evaporated Volume and the annual water surface area in the Bin El Ouidane dam reservoir 1976/77 – 2012/13.

3.2 Volume of the Water in the Reservoir

For the period 1976-2013, the figure 9 shows the strong correlation between the water supplies to the reservoir and the volume of water stocked. The evolution of the volume of water in the reservoir has experienced, with a gap of one hydrologic year, the same form of supplies evolution. This is related to the current method of reservoir management practiced in this dam, and by the way in all Moroccan large dams. In fact, the annual release program defined at the beginning of each hydrological year, is determined by two important factors: the statistically estimated water supplies during the current year and the amount of water supplies observed in the last year. As a result of that, the dry period of 1976-1995 shows a general decrease of the volume of water in the reservoir, because of the reduction of supplies. Then, the next period, which is much more humid, helped to augment this variable.

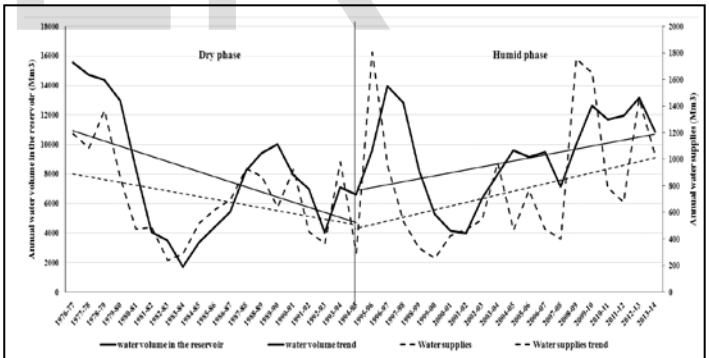


Fig. 9. The annual Volume of water in the reservoir and water supplies to the dam of Bin El Ouidane 1976/77 - 2013/14.

To assimilate the effect of both dry and humid stages on the filling of the Bin El Ouidane reservoir, we established the curve of the frequency of the monthly filling of the reservoir before and after 1995 (Fig.10). We observe, for example, that for the dry period 37 % of months show at least half filled reservoir, while during the humid period, it is about 54 % of months.

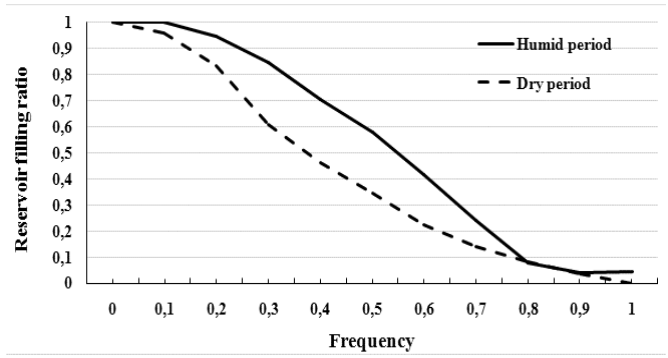


Fig. 10. Frequency of filling of the Bin El Ouidane reservoir during the dry and humid periods 1976/77 - 2013/14.

3.3 Turbinated Volume

The turbinated volume (released for irrigation and hydroelectricity production) follows the same evolution as the reservoir, with two phases:

- The dry phase prior to 1995, during which this variable has decreased as a direct result of the reduction of water in the reservoir;
- The humid phase post 1995, the volume of water filling level has increased to meet increased demand (Fig.11).

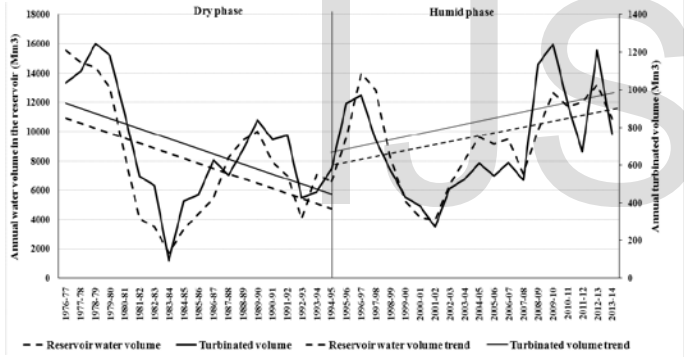


Fig. 11 The annual Volume of water in the reservoir and the turbinated volume at the dam of Bin El Ouidane 1976/77 - 2013/14.

3.4 Volume Allocated to Irrigation

The volume allocated for irrigation (this volume is turbinated twice in its way to crops) presents an overall upward trend during the period 1976-2011. Nevertheless, we can always distinguish the effect of the two phase identified for water supplies and rainfall discussed above. These phases are concretized this time not with a reversed trend but with the slope of the irrigation increase trend. In fact, during the period before 1995, and despite the lack of water supplies caused by long droughts, the managers decided to dedicate the majority of the turbinated volume to the partial satisfaction of agricultural demand, instead of the hydropower needs which stay optional. Thus, we find that the trend of the volume allocated to irrigation has increased, but in light slope to divide the available water volume rationally overall the dry period. After 1995, and with the filling of reservoir, the trend of increase of the volume of irrigation accelerated, to satisfy the growing water demands linked to the development of the agricultural irrigated perimeters around the dam, precisely: Beni-Moussa and Tassaout downstream, favored by the succession of the years with remarkable pluviometry (Fig.12).

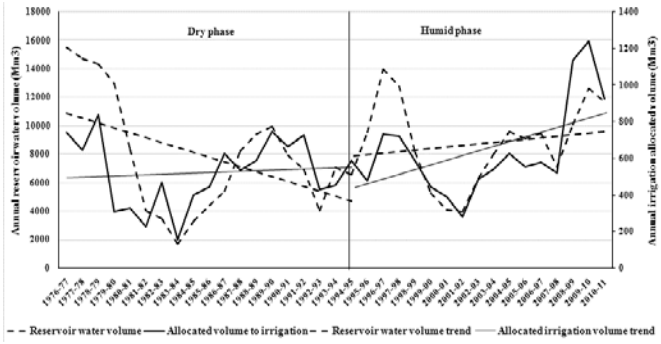


Fig. 12. The annual volume of water in the reservoir and that allocated to irrigation in the dam of Bin El Ouidane 1976/77 – 2010/11.

3.5 Mud silting of the Dam

By comparing both values of active storage volume corresponding to the initial state of the reservoir (1953), and that calculated from the elevation-area-volume curves established in 2003, we determined a reduction of the active storage estimated to 10.9 %, that is a rate of siltation of almost 2 Mm^3/year (Table 1).

This rate of siltation should be taken into account in any further reservoir management adaptation to CC, so that the manager will not overestimate his water stock.

4 Conclusion and Perspectives

TABLE 1. Mud silting of the dam of Bin El Ouidane between 1953 and 2013.

	Initial (1953)	Current (2013)
Level of the active storage m	810	810
Active storage of the reservoir	1384	1233,10
Mud silting Mm^3	150,90	
Mud silting %	10,90	
Average annual mud silting rate	1,94	

This analysis has shown how evolved the hydro-climatic context around the Bin El Ouidane dam for more than 70 years, with decreasing water supplies to the reservoir between the period before and after 1975.

The climate behaviour in the region resulting from this analysis, during last decades, follows the major trends presented in the IPCC 5th report. With an uninterrupted and accelerated warming, a stronger associated evaporation, a global increase of the rainfall which is nevertheless characterized by an alternation of dry et humid periods, and even sometimes very humid ones (as it is the case since a dozen of years) and a rainfall balance still showing a deficit.

The water reservoir management followed this hydro-climatic cycle, with water allocations to irrigation that re-

mained conditioned by the climatic nature of the years (dry or humid). In general, this allocation increases considering the strong increase of irrigation demand to fit the development of the region of Tadla-Azilal that depends on it. The management of the Bin El Ouidane dam was made in a reactive way, and could have been more efficient if the CC had not begun to destabilize the climate of the region and its water system.

The anticipative aspect of the current reservoir management approach, based on historical data will be less and less possible. The use of climate models associated to hydrological models to predict the future rainfall and expected water supplies to these reservoirs is highly recommended [Kundzewicz, 2009], [Bruwier 2013] and [Baptiste, 2013] and It is the key of the success of a sustainable management of waters of these dams in the context of water scarcity, which characterizes the region.

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