Preliminary analysis of Alvito-Odivelas reservoir system operation under climate change scenarios

Rani D., Moreira M.M., Mourato S.

in

López-Francos A. (ed.).
Drought management: scientific and technological innovations

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 80

2008
pages 133-138

Preliminary analysis of Alvito-Odivelas reservoir system operation under climate change scenarios

D. Rani*,[1], M.M. Moreira* and S. Mourato**
*University of Évora, Núcleo da Mitra, 7002-054, Évora, Portugal
**Polytechnic Institute of Leiria, 2411-901 Leiria, Portugal
[1]Corresponding author. E-mail: deeptinatyan@yahoo.com

SUMMARY – The present study provides a preliminary analysis of the impact of climate change on a water resources system of Alentejo region in the South of Portugal. Regional climate model HadRM3P forced by the Global Circulation Model HadAM3P A2 of the Hadley Centre, is used to derive temperature and precipitation data, which in turn is used as input to hydrological model (SHETRAN) for simulation of future streamflow. Dynamic programming based models are used for operation of reservoir system in order to examine the impact of climate change. Results are obtained for future streamflows and observed historical series, in order to analyze the performance of system operation in climate change scenario.

Key words: Climate change, optimization, dynamic programming, reservoir operation.

Introduction

Projections for the next decades, based on climate models, of the climate variables related to the water resources, are: increase in temperature, variation of precipitation patterns, increase of the intensity and frequency of the extreme precipitation events and sea level rise. Findings of Intergovernmental Panel on Climate Change (IPCC, 2001) strongly suggest that water resources will respond to global warming in ways that will negatively impact water availability and water supplies. Studying the impacts of climate change on water resources is complex as it varies with time and locations. Alentejo region in Portugal is facing drought since several last years, according to a European Environment Agency (EEA) technical report (EEA, 2007), average run-off and water availability in Southern European rivers are likely to decrease due to increasing temperature and decreasing precipitation in contrast to the Northern part. Therefore it seems worthy to study the impact of climate change on performance the water resources system of this region.

In general, climate change impact analysis uses a sequence of models to relate climate change at the global scale to water resources impact at the basin scale (Wood *et al*., 1997). This sequence typically begins with a coupled general circulation model (GCM) which predicts estimates of future changes in climate variables such as, precipitation and temperature. A downscaling method is then used to relate regional GCM output to climate variables at river basin scale which are used to force a hydrologic model to produce future streamflow scenarios. Streamflow scenarios serve as input data to models to evaluate the performance of a water resources system. In this paper, future streamflows are generated for the A2 climate change scenario using the physically based spatially distributed hydrological model SHETRAN. The climate data was obtained from Regional Climate Model (RCM) HadRM3P forced by the Global Circulation Model (GSM) HadAM3P A2 of the Hadley Centre-UK Met Office. Between the data observed for the control period (1961-1990) and the data of the climate model (2071-2100) a reduction of 30% in the average annual precipitation and an increase of 3.7°C in the average temperature are verified. Dynamic programming (DP) based models are used for operation of reservoirs which use both observed historical and future streamflow scenario to assess the impact of climate change on system performance.

Study system

The Alvito-Odivelas reservoir system is located in Ribeira de Odivelas River Basin in Alentejo region, Portugal. The maximum water level for Alvito and Odivelas reservoirs are 197.5 and 103.0 m, with gross capacities of 132.5 and 96 million m^3, respectively. The active/live and dead storage capacities of Alvito and Odivelas are 70 mcm and 26 mcm, and 130 mcm and 2.5 mcm, respectively. Alvito reservoir supplies water for public and domestic water demands of municipalities of Alvito, Cuba, Portel, Viana of Alentejo and Vidigueira. Regulated water from Odivelas reservoir is used to irrigate 6845 ha area and if the water available at Odivelas is insufficient to meet irrigation demands then the required amount of water is transferred from Alvito reservoir to Odivelas reservoir, through the river.

Climate data and future stream flow generation

The climatic data used were daily observed values of precipitation at Cuba, Ferreira do Alentejo, Portel and Viana do Alentejo rainfall stations for the period 1961-1990. In the evapotranspiration calculation daily temperature data from Viana do Alentejo meteorological station were used. The results of the RCM were bias corrected in order to be used in the hydrological model SHETRAN (Mourato *et al.,* 2008b). Between the observed data for the control (1961-1990) and the data obtained from the RCM for the period (2071-2100), a 30% decrease in precipitation and an increase of 3.7°C in the average temperature was found.

The hydrological model was calibrated for the entire basin with the daily flow data available in Odivelas River gauges (www.snirh.pt) and for the hydrological year 1964-1965 (dry year) and 1965-1966 (wet year). A comparison of the observed historical monthly inflow for the period 1961 to 1973 and generated inflow by the model based on climate model for the control period at Odivelas reservoir showed that generated inflow resulted in lower flow in most of the cases (Mourato *et al.,* 2008a). Figure 1 presents the monthly inflow to the reservoirs in historic (1952-1973) and future climate change scenario (2071-2100). Average monthly inflow reduction occurs during wet season which varies from 20 to 95%, however, an increase in monthly inflow during dry season is also observed for both reservoirs. This shows that monthly distribution of inflows may also vary in climate change scenario. An average overall annual reduction of about 90% in the simulated monthly volumes is found for the period 2071-2083 as compared to the inflow for the period of 1961-1973 for both reservoirs. The reduction is very high and this difference may have been increased because of calibration errors, choice of a less accurate method for determination of evapotranspiration and even from the RCM data, however, similar results were also reported in a study by Nunes *et al*. (2007) for watersheds in Alentejo region. Nonetheless, these results aware about the importance of studying measures to adapt to the decrease in the availability of water resources.

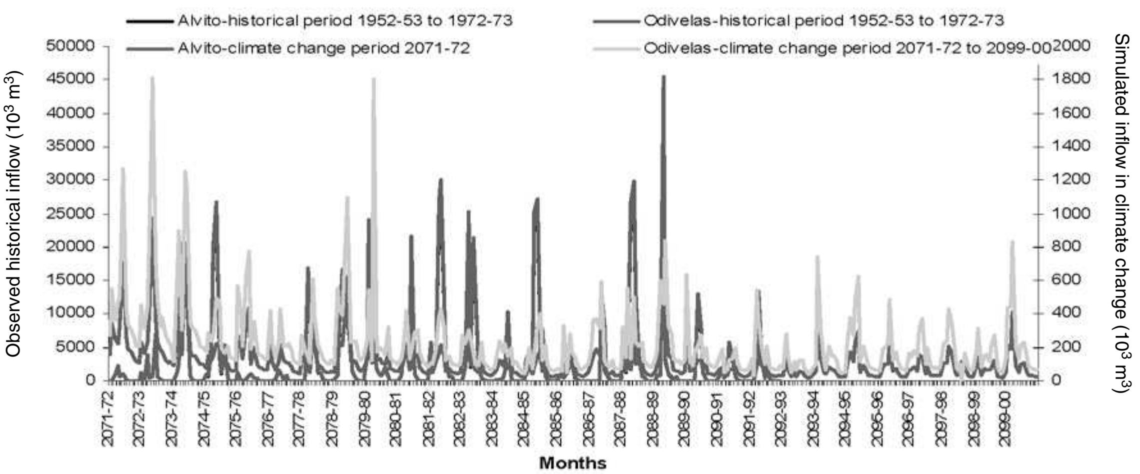

Fig. 1. Monthly inflow volumes at Odivelas and Alvito reservoirs.

Reservoir system operation models

Two DP based models are used for reservoir system operation optimization. Conventional DP models are used for reservoir operations while a procurement based water import DP model (WIM) is applied at Odivelas reservoir to determine the amount of water to be imported into reservoir to meet its water demands fully (Deepti Rani, 2004; Deepti Rani *et al.*, 2005). The general backward moving WIM formulation is as follows:

$$f_r(S_r) = \underset{Q_r^{IM}}{\text{Min}} \left[g_r(S_r, Q_r^{IM}) + f_{r-1}(S_{r-1})\right] \qquad \forall\, r \qquad (1)$$

Subject to

$$S_{r-1} = S_r + Q_r^{IM} + Pp_r + I_r - EV_r - (D_r + Sp_r), \qquad \forall\, r \qquad (2)$$

$$Q_r^{IM} \geq 0, \qquad \forall\, r \qquad (3)$$

$$0 \leq S_{r-1} \leq Y_a, \qquad \forall\, r \qquad (4)$$

$$Sp_r \geq 0, \qquad \text{if} \qquad Q_r^{IM} = 0, \qquad \forall\, r \qquad (5)$$

where index r (stages to go, from backward) is used to for backward recursion in DP; $f_r(S_r)$ represents recursive function, the summation of all the minimum values of cost functions, from all r stages to go. Q_r^{IM}= amount of water import from reservoir/source to importing reservoir to meet its target demands fully in r stages to go; $g_r(S_r, Q_r^{IM}) = C_r^{IM} \times Q_r^{IM}$ is cost function for r stages to go; C_r^{IM} = unit cost of water import in r stages to go; S_r = reservoir storage at beginning of r stages to go; S_{r-1} = reservoir storage at end of r stages to go; I_r = total inflow into reservoir in r stages to go; D_r = total demand at reservoir in r stages to go; Y_a = live or active storage capacity of reservoir; Sp_r is spill or unutilized water in r stages to go; Pp_r = precipitation over reservoir surface and EV_r = evaporation losses from reservoir in r stages to go.

For reservoir operation DP models the overall objective is to minimize the sum of total squared deviation from target demands subject to continuity equation and other constraints. Firstly, WIM for Odivelas reservoir is solved to estimate the amount of water import needed from Alvito reservoir. Results obtained from water import model, are used as demand in Alvito reservoir operation model. In case of Alvito operation priority is given to first meet ecological flow requirement of the river followed by municipal water supply and then import demand of Odivelas.

Results and discussion

Water import model results show that total demand at Odivelas including ecological requirement and evaporation losses exceeds the inflow and therefore the amount of water need to be imported from Alvito is more than irrigation demand in climate change scenario (Fig. 2). Average annual water import requirement increases by 180% as compared to historical results. This shows that evaporation losses are quite high and in addition to irrigation, water import is required to meet ecological flows as well.

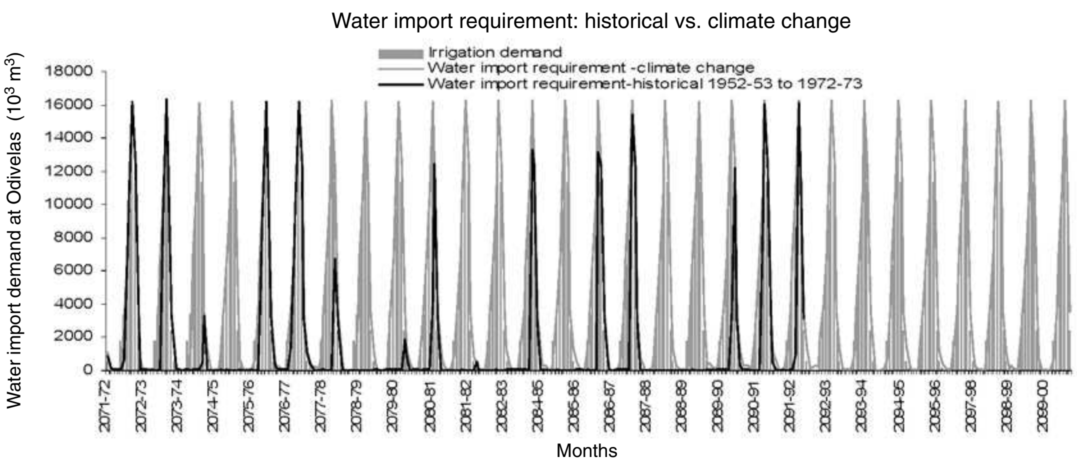

Fig. 2. Water import requirement at Odivelas in historical and climate change scenario.

Further, due to very low inflow it is not possible to transfer any water to Odivelas in climate change scenario, while except some dry years this demand is usually met for historical period. In fact, Alvito can not supply water to meet municipal demands in climate change situation even if the demand is reduced by 90% of the current value (Fig. 3). In all above mentioned studies reservoir was assumed to be empty at the beginning of the study period. If reservoir is assumed to be full at the beginning in climate change scenario, Alvito can supply water to meet municipal water needs only up to 10 initial consecutive years. And in this case too if demand is reduced by 90% then this period can be increased up to 13 consecutive years only (Fig. 4). This clearly confirms the losses of the water through evaporation, as evident from Fig. 5.

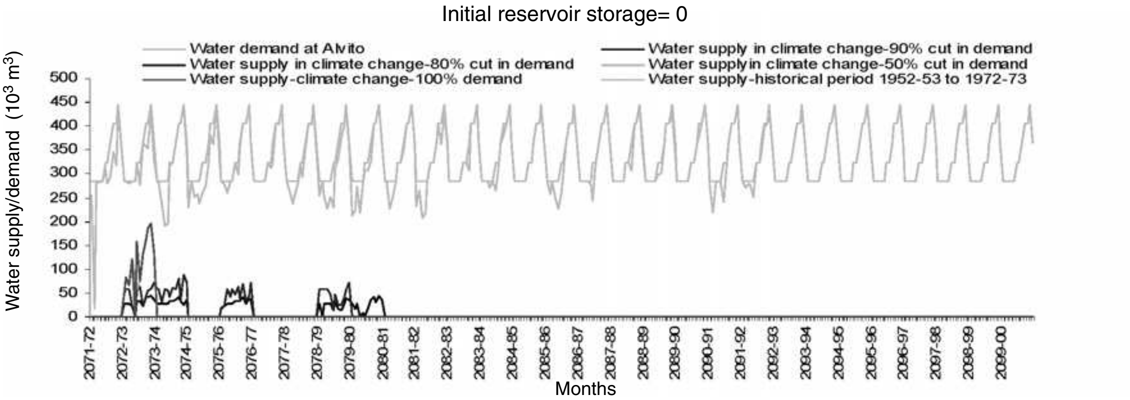

Fig. 3. Municipal water supply from Alvito in historical and climate change scenario if reservoir is empty at the beginning of the study period.

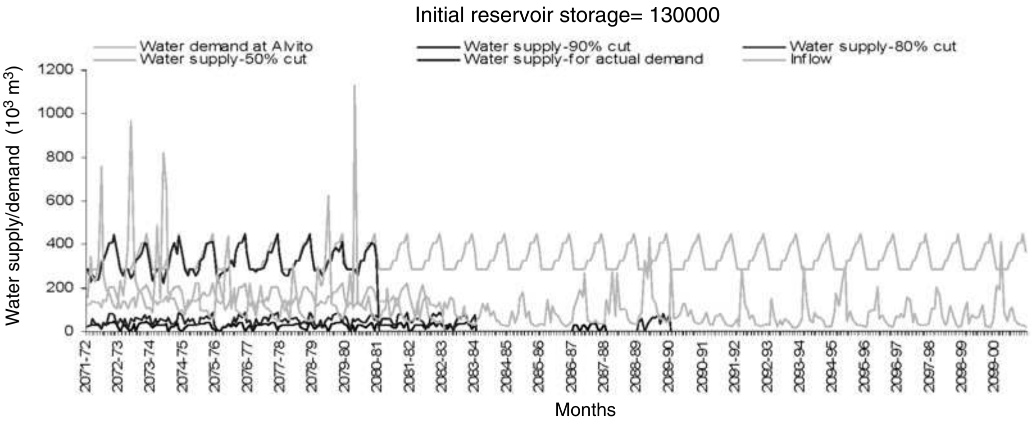

Fig. 4. Municipal water supply from Alvito in climate change scenario if reservoir is full at the beginning of study period.

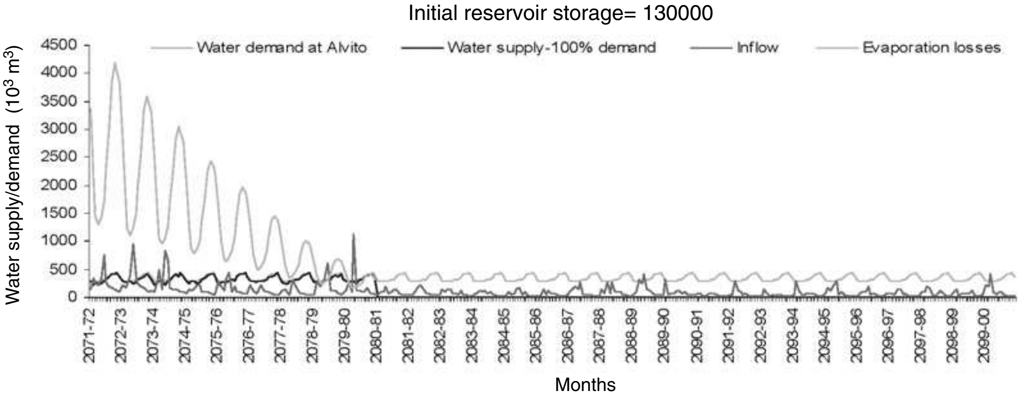

Fig. 5. Evaporation losses at Alvito in climate change scenario if reservoir is full at the beginning of the study period.

These results show that the performance of reservoirs would be significantly influenced by evaporation losses, which would be higher in warmer climate, which suggest that it would not be beneficial to built storages in reservoirs. In this study however, evaporation losses estimation in climate change scenario was based on temperature only, and this need to be re-estimated more accurately using some sophisticated method involving other climatic data.

Conclusions

This paper accounts preliminary assessment of the impacts of climate change on Alvito-Odivelas water resources system. The results are obtained by inputting the output of RCM and physically based hydrologic model to DP based reservoir operation models. The initial findings show that future climate situation may drastically degrade the performance of the system, as per climate model predictions used in this study. The system would not be able to meet municipal water demands even if the demands are reduced by 90% as compared to the current demands. The total demand (including evaporation losses) found to exceed reservoir inflows to a great extent. While it is reported that the reliability of a reservoir system decreases rapidly as demand approaches the mean inflow (Christensen *et al.*, 2004). Therefore situation would, in fact, be worse as demands are predicted to increase in future. Results indicate that the performance of reservoirs would be significantly influenced by evaporation losses, which would be higher in warmer climate, concluding that it would not be beneficial to built storages in reservoirs. In this study, however, evaporation losses estimation for climate change was based on temperature only, and need to be re-estimated more accurately using some sophisticated method.

Acknowledgments

Financial support provided by the Fundação para a Ciência e a Tecnologia (FCT), Portugal for postdoctoral grant (SFRH/BPD 26929/2006) is gratefully acknowledged.

References

Bathurst, J.C., Kilsby, C. and White, S. (1996). Modelling the impacts of climate and land use change on basin hydrology and soil erosion in Mediterranean Europe. *Mediterranean Desertification and Land Use*, C. J. Brandt and J. B. Thornes. Chichester, John Wiley and Sons Ltd. 355-387

Bathurst, J.C., Ewen, J., Parkin, G., O'Connell, P.E. and Cooper, J.D. (2004). Validation of catchment models for predicting land-use and climate change impacts. 3. Blind validation for internal and outlet responses. *Journal of Hydrology,* 287: 74–94.

Christensen, N.S., Wood, A.W., Voisin, N., Lettenmaier, D.P. and Palmer, R.N. (2004). The effects of climate change on the hydrology and water resources of the Colorado river basin. *Climate Change*, 62: 337-363.

Deepti Rani (2004). *Multilevel optimization of a water resources system*. PhD Thesis, Dept. of Mathematics, Indian Inst. of Tech., Roorkee, India.

Deepti Rani, Srivastava, D.K. and Gulati, T.R. (2005). Derivation and Selection of Intra-Basin Water Transfer Policy for PAV Link Project. In: *Proc. XII World Water Congress of IWRA – Water for Sustainable Developments–Towards Innovative Solutions*, New Delhi (India), 22-25th November 2005.

European Environment Agency, EEA (2007). *Climate change and water adaptation issues*. Technical report No. 2/2007.

Ewen, J. and Parkin, G. (1996). Validation of catchment models for predicting land-use and climate change impacts. 1. Method. *Journal of Hydrology,* 175: 583-594.

IPCC (2001). *Climate change 2001: The scientific basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, http://www.ipcc.ch/ipccreports/tar/wg1/index.htm.

Mourato, S., Deepti Rani, Moreira, M. and Corte-Real, J. (2008a). A exploração dos recursos hídricos no sistema Alvito-Odivelas para um cenário de alteração climática. Workshop Internacional sobre Clima e Recursos Naturais nos países de língua portuguesa: Parcerias na Área do Clima e Ambiente (WSCRA08). Ilha do Sal.

Mourato, S., Moreira, M. and Corte-Real, J. (2008b). Correcção de viés em modelos regionais de clima e impactes na modelação dos recursos hídricos. 9º Congresso da Água. Cascais.
Nunes, J.P., Seixas, J. and Pacheco, N.R. (2007). Vulnerability of water resources, vegetation productivity and soil erosion to climate change in Mediterranean watersheds. *Hydrological Processes,* DOI 10.1002/hyp.6897.
Wood, A.W., Lettenmaier, D.P. and Palmer, R.N. (1997). Assessing climate change implications for water resources planning. *Climate Change*, 37: 203-228.