

Water resources of the Mediterranean basin: current state and future estimates.

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For the past twenty years, quantifying the impacts of climatic and socio-economic changes on water resources have been of fundamental concern to scientists and water managers worldwide. Global analyses of the impacts of climate change, population growth and water withdrawals on water availability for the 21st century were carried out (e.g. Arnell, 2004; Alcamo *et al.*, 2007; Menzel & Matovelle, 2010). The results showed that the Mediterranean region is one of the most vulnerable regions to water crisis.

The Mediterranean basin is characterized by unequally distributed water resources, as well as by important development of its anthropogenic activities. Future scenarios suggest an increase in temperature of 2°C by the 2050s, a decrease in average rainfall and then more frequent and intense drought periods, which should induce a progressive decrease in average annual streamflows. Moreover water demand in the Mediterranean basin has doubled since the late 1950s and should remain on a constant upward curve due to a significant expansion of irrigated land and urban areas (Plan Bleu, 2005). Water demands in its various uses should hence become increasingly difficult to meet.

In order to analyze the impacts of climatic and human pressures on current and future Mediterranean water stress, a methodology was developed and applied to Mediterranean watersheds (Milano *et al.*, 2011; *subm.*). Mediterranean water resources' vulnerability evaluation was assessed using a water stress index. It is based on the ratio of annual water withdrawals to annual renewable water resources availability (Shiklomanov, 1991). Over the current period, the conceptual rainfall-runoff Water Balance Model (Yates, 1997) was applied to evaluate freshwater availability, and an overview of agricultural and domestic water withdrawals was completed according to national reports. To evaluate the future trends in water availability at short (2025) and mid (2050) terms, climatic scenarios were generated on the basis of the "deltas" or perturbation method (see e.g. Etchevers *et al.*, 2002; Prudhomme *et al.*, 2002; Shabalova *et al.*, 2003), using projections from four global climate models. These climatic scenarios were used as inputs to the hydrological model but also to the irrigation management model CROPWAT (Allen *et al.*, 1998) in order to evaluate future agricultural water withdrawals. Domestic water withdrawals were estimated using the A2 demographic scenarios (UNPD, 2001). This methodology was applied over two future scenarios, which diverge in hydraulic efficiency assumptions. The first scenario ("business-as-usual") considers that current efficiencies of networks and irrigation plots' are upheld, while the second scenario (alternative) introduces improvements in transport and distribution networks and irrigated plots' efficiencies based on the Mediterranean Strategy for Sustainable Development (MSSD; UNEP-MAP, 2006).

Results show that the southern and eastern rims of the Mediterranean basin are currently stated as being under a high to severe water stress. Water resources vulnerability is expected to increase in these areas. Total water withdrawals are projected to double by the 2025 horizon under a "business-as-usual" scenario, due to high population growth and expansion of irrigated land. Improvement in efficiency should hold down freshwater withdrawals. Nevertheless, compared to their current level, total water withdrawals in the southern and eastern catchments should still increase and these catchments should still experience very high water stress. The water stress state could only be maintained at its current level in catchments in Turkey. In the northern rim, water stress currently varies between moderate and none. Even though agricultural withdrawals are expected to increase due to warmer and drier conditions, the current state should remain as is by the 2025 horizon. Water stress is projected to improve only in some catchments in Italy due to efficiency improvements as well as a projected decrease in population growth. By the 2050 horizon, water stress should increase over the whole Mediterranean basin, mostly as a result of a 30 to 50% decrease in freshwater resources.

According to these results, the water stress situation over the Mediterranean basin could quickly evolve to very high water stress. However, progress in networks' and plots' efficiencies could

significantly limit water withdrawals, at least in the short term. Given the highly non-stationary climatic and anthropic conditions over the Mediterranean basin, and the number of limitations linked to the methodology used, these results must be qualified.

With regards to the tools used, a first uncertainty comes from the fact that the Water Balance Model does not precisely account for groundwater resources. Water stress might thus have been overestimated, notably in some southern catchments, although more than a fourth of the water supplies come from non-renewable water resources in these areas. Another uncertainty comes from the future climatic data. Input data for future estimations are based on global datasets with coarse spatial resolution. Due to their low resolution, global climate models cannot capture fine-scale meteorological processes that influence precipitation patterns. Moreover, different climate models yield different scenarios for the same set of future conditions. However these biases were reduced by applying corrections and by working with outputs from four global climate models. Concerning freshwater withdrawals, the main uncertainty comes from simplification of the social and economic processes. Per unit water demand was assumed to be constant over an entire country. No changes in the types of irrigated crops were considered. Yet agricultural water demand depends heavily on factors lying outside the water sector, such as agricultural policies and international trade characteristics (see e.g. Treyer, 2006; Fernandez, 2009). Moreover, the efficiency objectives considered in this study may be judged overly ambitious. Nevertheless, the beneficial effects of such improvements in water withdrawals draw attention to the importance of water-saving policies. Finally, only irrigated agriculture and the domestic sector were taken into consideration, whereas the industrial sector has a large contribution in water withdrawals in the Balkans and Algeria, for example.

Despite these limitations, these analyses provide a first overview of the Mediterranean water resources vulnerability. Possible evolution trends have been assessed, which may be useful for identifying catchments that are most likely to be under pressure. Such a study is also a first step toward broader-perspective studies involving contrasting scenarios. It can help in setting up regional adaptation strategies to cope with water stress, as in the efficiency objectives advocated by the MSSD. To support adaptation water management plans and meet users' needs, more Mediterranean specificities should be taken into account (e.g. industrial water use, dams, tourism) with a more local-scale perspective. This is the subject of ongoing research.

For more information on this study, one is referred to the following papers:

- Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Ardoin-Bardin, S., Fabre, J., Thivet, G. & Servat, E. (2011) Assessing the impacts of global changes on the water resources of the Mediterranean basin. In: *Risk in Water Resources Management*. IAHS. Publ. **347**, 165-172.
- Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Ardoin-Bardin, S., Fabre, J., Thivet, G. & Servat, E. (2012) Current state of Mediterranean water resources and future trends under global changes. *Global Environ. Change*. *subm.*

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UNPD – United Nations Population Division (2001) United Nations Population Information Network. <http://www.un.org/popin/>.

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Acronyms

MSSD – Mediterranean Strategy for Sustainable Development

UNPD – United Nations Population Division

UNEP-MAP – United Nations Environmental Program – Mediterranean Action Plan