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Climate change impact on the water resources of the semi-arid Jordan region

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ABSTRACT

The paper deals with the simulation of current water availability and irrigation water demand in the semi-arid part of the Jordan River Region. It also includes an assessment of the impact of future climate change on the regional water resources. The investigations are based on the IPCC B2 scenario and cover the scenario period 2070–2099. First simulations indicate drastic changes in the future distribution and availability of the region’s water resources. A projected ca. 11% decrease of future precipitation totals leads to simulated reductions in water availability of ca. 25%, and irrigation water demand would rise by about 22% in order to sustain agriculture at its current extent.

INTRODUCTION

In the framework of the “GLOWA-Jordan” project (www.glowa-jordan-river.de), an interdisciplinary and multinational group of researchers investigate the impact of climate and land-use change on the water resources of the Jordan Region. The area investigated in the hydrological sub-project includes the semi-arid part of the Jordan basin and its broader environs. Thus, it is stretching from the upper north of the Jordan basin to the Gulf of Aqaba in the south, and from the Mediterranean coast to the Jordanian Highland / Jordanian Plateau (Fig. 1), and covers a land area of approximately 90,000 km².

The Jordan River Region is ranking among the most water poor regions of the world. Over a distance of only 300–400 km a pronounced climate gradient occurs, with climate conditions changing from sub-humid in the north of the region (mean annual precipitation ca. 800–1000 mm) to hyper-arid at the Red Sea (mean annual precipitation less than 100 mm, potential evaporation > 2000 mm). The scarce water resources are competitively shared among several nations and different water use sectors, with irrigation agriculture as one of the major water users: Around 66% of the current water use is for irrigation purposes, and ca. 30% is used in the domestic sector (EXACT, 1998). These numbers are however unevenly distributed over the different countries. While the mean daily per capita domestic water use amounts to 250 litres in Israel, the related numbers for Jordan and the West Bank are 90 litres and 55 litres, respectively. An increasing population with a current number of ca. 16 million, rising water demands and an expected reduction in precipitation totals make the region susceptible to frequent droughts and future water conflicts.

Our investigations aim to assess the impact of both land-use and climate change on the water resources of the project region. They include selected field studies and hydrological simulations on different spatial scales, from the patch scale to the hydrological meso- and macro-scale (Fig. 1). The small to medium scale studies serve to further develop and validate the applied hydrological model regarding the representation of evapotranspiration, irrigation water demand, soil moisture and groundwater recharge. The application of the hydrological model to the macro-scale serves to carry out an areal analysis of the water balance elements and their modification by land-use and climate change. Therefore, the investigation considers two time periods: The reference period covers the years 1961–1990, while the scenario conditions refer to the period 2070–2099.

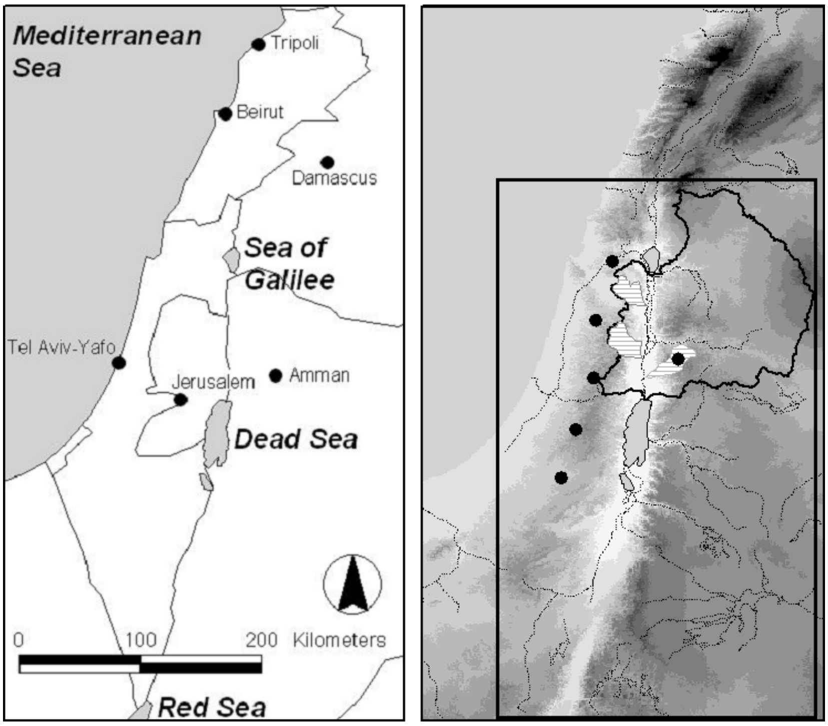

Figure 1. Overview of the Jordan River Region, including frontiers and big cities (left) as well as the topographical conditions (right). The square on the right graph encloses the actual project region and includes the semi-arid sub-basin of the Jordan River (located between the Sea of Galilee and the Dead Sea, with catchment borders drawn as solid line) as well as several experimental sites (black dots) and meso-scale research catchments (hatched)

METHODS

The investigations in the project region have been carried out with the hydrological model TRAIN. TRAIN is a physically-based, spatially distributed model which includes information from comprehensive field studies of the water and energy balance of different surface types, including natural vegetation and agricultural land. It has been designed to simulate the spatial pattern of the individual water budget components at different spatial and temporal scales. Typical applications are at the point and the regional scale, with temporal resolutions of one hour or one day. For an areal simulation of the water budget, the investigated spatial unit is subdivided into a regular grid, with square sizes dependent on the available input data and their spatial resolution (typically in the range of 1 x 1 km). Special focus in TRAIN is on the processes at the soil-vegetation-atmosphere interface, with evapotranspiration as one of the principal mechanisms. For the regionalisation of the water balance components specific local elements (topography, land-use, soils) and varying meteorological conditions are included in the calculation process (Figure 2).

At the core of the model is the simulation of transpiration through plants based on the Penman-Monteith equation (Monteith, 1965). It depends on the calculation of canopy resistances which are modified by the state of growth of the vegetation, soil moisture and weather conditions (Menzel, 1996). Interception and interception evaporation are simulated according to Menzel (1997). This approach subdivides the canopy into an optional number of layers from which the intercepted water can evaporate with different intensities. This is especially an advantage regarding the representation of water fluxes in dense canopies. In the case of poor soil information the calculation of the soil water status and of percolation follows a modified version of the conceptual approach from the HBV-model (Bergström, 1995). In other cases, the soil module includes the storage routing technique described by Arnold et al. (1990) which subdivides the soil into a number of discrete layers. The snow accumulation and snow melt schemes are based on simple, conceptual approaches, such as the degree-day equation. Melted snow is treated in the same way as rainfall for further calculation of infiltration/percolation. Application of TRAIN for agricultural land includes the consideration of a number of different field crops and possible irrigation water demands. As soon as the soil water content falls below a critical limit, the model assumes the application of irrigation as long as a sufficient soil water status (usually field capacity) is not reached. The amount of water needed to compensate soil water stress is assumed to equal irrigation water demand.

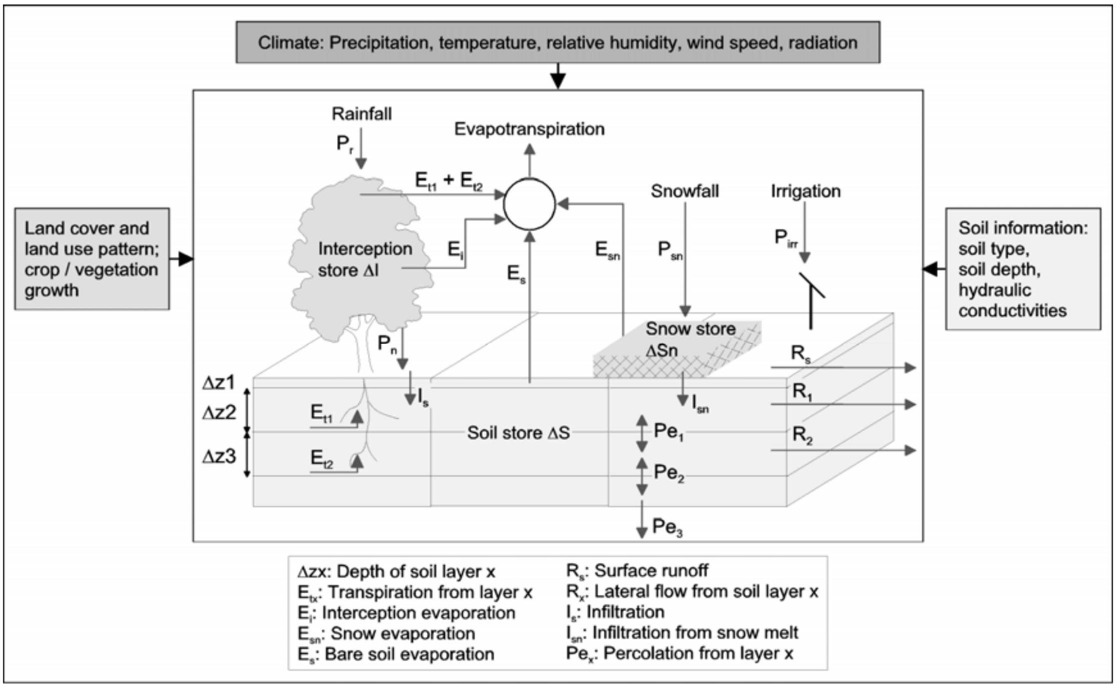

Figure 2. Overview of the TRAIN model, its input requirements, the simulated processes and the related output data

For an areal analysis of the water balance of the semi-arid Jordan region a series of data sets was required to drive the TRAIN model: Daily meteorological data (precipitation, air temperature, air humidity, wind speed and solar radiation) were adopted from MM5 climate model runs (see below). Information regarding topography was taken from the global Digital Elevation Model (DEM) GTOPO30 (USGS, 2007a) with a horizontal grid spacing of 30 arc seconds (approximately 1 km). Since no integrative, consistent land-use and soil data base was available for the three countries of the project region, respective global data sets were applied. Land use information came from the Global Land Cover Characterization GLCC (Loveland et al, 2000; USGS, 2007b) with a grid size of 1 x 1 km. Data from the Soil Map of the World database (FAO, 1991) with a 5 arc second spatial resolution were combined with predictions of profile available water capacity as described in Batjes (1996). The DEM, the soil and land-use grids and the individual climate layers were re-projected to congruent grids and aggregated to a common spatial resolution of 18 x 18 km. This was necessary since the data delivered by the climate model were available at this resolution, thus allowing only a comparatively coarse areal analysis. However, information on sub-grid variability was taken into account, i.e., TRAIN was iteratively run for individual grid cells which contain heterogeneous soil and land-use conditions.

Meteorological time series for both the reference period 1961–1990 and the scenario period 2071–2099 were delivered by the Institute for Meteorology and Climate Research IMK-IFU (http://imk-ifu.fzk.de/) on a 18 x 18 km grid. They are based on multiple runs of the limited-area, meso-scale climate model MM5 (MM5, 2007) which was driven with boundary conditions from the Global Climate Model ECHAM4 (Roeckner at el, 1996) and thoroughly tested against observations available for the project region. The climate scenarios are based on the IPCC A2 and B2 emission scenarios. In the present paper, focus is only on results of the B2 related scenario data since climate model output was not available yet for A2.

RESULTS

Figure 3 presents the mean monthly rainfall distribution in the focus area, calculated using daily data generated by the MM5 model. Data are shown for both the reference and the scenario period. In general, rainfall is very unevenly distributed over a year, with a clear maximum during winter and practically no rainfall during the summer months (Fig. 3). According to the applied climate scenario, this inter-annual variability will be preserved in the future, but the mean annual rainfall totals are projected to decrease – from 141 mm during 1961–1990 to 125 mm during the scenario period. According to the scenario, mean monthly rainfall is projected to increase during May, June and October; however, the absolute changes are small and they are considered to lie within an estimated uncertainty range.

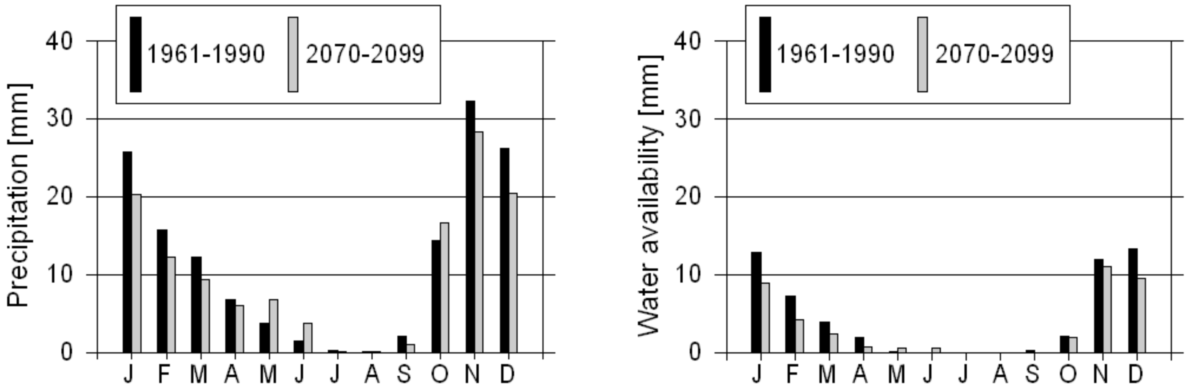

Figure 3. Overview of the water resources of the investigated region and their modification by climate change. The figure shows mean monthly precipitation totals (left) and mean monthly water availability (right) for both the reference and the scenario period, the latter based on IPCC's B2 emission scenario. Precipitation data come from the MM5 model while water availability is generated using output from TRAIN

Figure 3 also shows the water availability simulated by TRAIN (understood here as a combination of cell specific groundwater recharge and runoff). In comparison to the rainfall data, water availability is much lower and exceeds a mean monthly threshold of 10 mm only during November–January of the reference period (Fig. 3). With the B2 climate scenario, water availability is simulated to decrease, with a reduction of mean annual totals from 54 mm during 1961–1990 to 40 mm during 2070–2099. The analysis clearly demonstrates the water scarcity in the region and that there seems to be a tendency towards a further reduction of water availability within the next decades. It should also be pointed out that the diagrams of Figure 3 show aggregated data over the whole project region (Fig. 1). It is clear however that several sub-regions suffer an even higher water shortage. The large difference between the precipitation and water availability data clearly demonstrates the importance of evaporative processes in the focus region.

Figure 4 presents further results regarding the impact of climate change on the area investigated. As in Figure 3, it can be stated that the projected reduction of mean annual precipitation (based on the MM5 model output, driven by the B2 emission scenario) leads to an over-proportional decrease of water availability in the region. Figure 4 reveals however that actual evapotranspiration is simulated to increase by 2% only. The reasons for this developments are as follows: Precipitation is projected to decrease relatively uniform over the project region. In the extremely dry, southern parts of the region, at the edge of the Negev desert or in the Negev itself, water availability is close to zero already under current climate conditions. A further decrease of precipitation doesn't therefore lead to any reduction in water availability in those regions. However, our simulations show a clear reduction in actual evapotranspiration. In the more humid, northern parts of the region and along the coastal plains, a reduction of precipitation leads to a strong decrease in water availability while actual evapotranspiration is projected to increase. Therefore, the inhomogeneous changes in evapotranspiration across the region are more or less balanced out in the aggregated view presented in Figure 4. In contrast, a strong net decrease follows for the water availability.

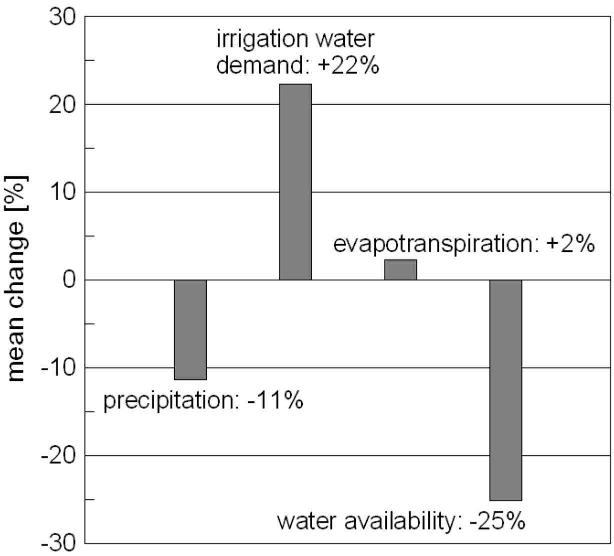

Figure 4. Aggregated results of the B2 scenario study for the investigated region. The graph depicts relative changes of the major water balance components and of irrigation water demand for the scenario period 2070–2099 in comparison to the reference period 1961–1990

Under the assumption of an unchanged extent and intensity of irrigated agriculture, the reduction in water availability would need to be adjusted by additional irrigation. Therefore, irrigation water demand is rising by the large, relative amount shown in Figure 4. The result doesn't argue however that this additional amount of water will be available under the future, obviously more water scarce conditions.

DISCUSSION AND CONCLUSIONS

The results presented in this study come from a first estimation of current and future water resources in the Jordan region and thus need to be considered as preliminary. They include several simplifications and assumptions as well as coarse datasets. Refinements and model improvements will be iteratively included in the simulations, and additional climate scenarios will be considered in order to give an uncertainty range regarding the possible future development of the water resources.

Given the discussed uncertainties, our study shows that the project region will very probably experience higher levels of water stress in the future. Even the relatively moderate B2 climate scenario results in a drastic decrease in water availability while irrigation water demand would rise accordingly in order to sustain agriculture at its current extent. Since the population numbers of the region are also projected to increase, a further rise in domestic and industrial water demand can be expected in the future. It is however very unlikely that additional freshwater resources will be available to close the gap between rising water demands and decreasing water availability. Options, such as seawater desalination, rainwater harvesting or wastewater irrigation are not considered in this study, but it is planned to include them in one of the next steps of the project. In any case, the investigations indicate that irrigated agriculture will very probably come to its limits under drier conditions. Scenarios of land-use change, such as a reduction of agricultural land, will soon be included in our investigations. Our study also aims at initiating and supporting measures towards an Integrated Water Resources Management in the region. However, this will only be successful when all affected parties are included.

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