The impact of water pricing in an arid river basin in Morocco considering the conjunctive use of ground- and surface water, water quality aspects and climate change

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Abstract

Climate change is likely to lead to more unreliable water supply in the future, especially in arid regions of the world. A hydro-economic river basin model is used to analyse the effects of an IPCC climate change scenario on water use and agricultural income in the arid Middle Drâa river basin in Morocco. The model considers problems of irrigation water salinity and the conjunctive use of surface and groundwater and their interconnections. We use REMO model data provided by the IMPETUS project (Speth et al. 2010) to derive a maximum likelihood density estimate of current and future water supplies that are introduced as a random variable into the mathematical programming approach for Monte Carlo simulations. The paper extends the work by Heidecke and Heckelei (2010) by simulating management options taking water pricing as an example. The effects on water use and different economic indicators are evaluated. Results show that climate change impacts negatively on irrigation water availability, and hence leads to a reduction in farm income. The effects of water pricing as a management option analysed depend on the assumptions of water quality of irrigation water, overall water supply and the scope of the water charge.

Keywords

climate change, conjunctive water management, hydro economic river basin models, water quality

Introduction

The impact of climate change on land use and water use has received increasing attention in research, especially with more data available from the IPCC (2007) report. According to IPCC by 2080 an increase of "5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios" (IPCC 2007: 50). The Middle Drâa valley in Southern Morocco is already facing semi-arid to arid weather conditions and is heavily relying on irrigation water for agricultural production in the six oases. Irrigation water is mainly drawn from the Mansour Eddabhi reservoir that is centrally managed to distribute water to the six oases along the Drâa River. During the last centuries water available from the reservoir has been decreasing due to less rainfall but also due to more demand and higher evaporation rates. Therefore, farmers have shifted to more groundwater use for irrigation. Groundwater is available from shallow aquifers below each oasis, which are connected due to a hydraulic gradient with each other (Klose et al., 2008). The specific setting of surface and groundwater availability and the interactions of groundwater aquifers as well as groundwater and surface water provide a challenging and complex system of conjunctive water use in the Middle Drâa valley. The economics of the conjunctive use of water have been analysed by economists since the sixties starting with simplified analysis by Buras (1963) and Burt (1964). The theoretical approach has since then been applied to various settings e.g. by Feinerman and Knapp (1984), Provencher and Burt (1994), Roseta-Palma (2006) and Gemma and Tsur (2007).

The conjunctive use of water in the Middle Drâa valley has been analysed with an optimization model by Heidecke et al. (2008) who set up an optimization model that allocates irrigation water between the six oases in an economic optimal manner. Heidecke and Heckelei (2010) used the model to analyse the effect of water quality and changing water inflow distributions under the assumptions of two climate change scenarios of the IPCC. In this paper we extend the work by Heidecke et al. (2008) and Heidecke and Heckelei (2010) to analyse water pricing as a management options under water scarcity and salinisation problems. Water pricing is mainly applied in developed countries. In developing countries or in countries facing water scarcity water pricing is controversially discussed as an economic tool to prevent water overexploitation. The FAO (2000) points out that the effectiveness of water pricing needs to be regarded behind the background of a comprehensive study that includes different exemptions. The Middle Drâa valley is a good example of a system where water pricing needs to be regarded carefully in the light of surface and groundwater interactions as well as the already existing high salinity rates in irrigation water and therefore, the economic effectiveness of irrigation water pricing. Therefore, we want to adress two questions in this paper.

Firstly, how does a groundwater pricing scheme affect agricultural income? This is a question that has already been analysed by Heidecke et al. (2008) for the Middle Drâa valley, but with a model version that did not incorporate water quality issues. They analysed in detail the difference of surface and groundwater pricing with respect to water use and agricultural income. However, water quality might influence the results. This shall be analysed in this paper.

Secondly, how does a water charge affect groundwater use in the different oases? For this we analyse a range of water charges in different settings and evaluate the effects in each oases separately. As water use is highly interactive in the Middle Drâa valley, water pricing needs to be regarded in the specific regional setting.

The paper is set up as follows. We first describe the data and the optimization model used with references to previous publications and model descriptions. We also describe groundwater pricing as a management options analysed in this paper. Then, we present some results of economic and hydrologic relevance. We end this paper with conclusions for water management in the Middle Drâa valley and elsewhere and point out the limitations of this modelling exercise.

Methodology

The model set up and applied for the Middle Drâa valley is described in detail by Heidecke et al. 2008. The use of climatic data within the model and the estimation of inflow distributions have been conducted by Heidecke and Heckelei (2010). In this section we briefly refer to the main characteristics of the modelling approach and then point out the adjustments for management options that have been added in this paper.

The optimization model is a comparative static optimization model that maximises total agricultural income calculated as the product of exogenous crop prices which could be received on local markets and production quantities, minus the production costs including costs for groundwater use. Surface water use is free of charge to the farmers. The model maximizes agricultural income over all six oases and for all major crops cultivated which are wheat, barley, maize, alfalfa, a vegetable aggregate, and henna and date palms as perennial crops. The model is solved for monthly periods and for one year simultaneously over all oases. The model is calibrated using the positive mathematical programming technique (PMP) (Howitt, 1995), but introducing supply elasticities as prior information in the specification step (Heckelei, 2002, Heckelei and Wolff, 2003). The elasticities for the perennial crops, date palms and henna, are more inelastic compared to the other crops as farmers give priority to these for financial reasons and try to preserve them in times of water shortage.

Water supply is coming from two sources: surface water and groundwater. Surface water is determined by the inflows into the reservoir where it can be stored and released to the oases each month. From there it is directed to the six oases. Groundwater is locally available in each oasis and determined by lateral inflows, irrigation and river water infiltration. Aquifers are also connected with each other according to specific flow gradients. Thus groundwater use in an oasis upstream affects groundwater availability in the oases downstream the river.

The stochastic nature of water availability is considered by available regional projections of precipitation under climate change scenarios A1B of the Intergovernmental Panel of Climate Change (IPCC, 2007) derived within the IMPETUS project (Speth et al. 2010) by Born et al. (2008) and Paeth et al. (2008) for southern Morocco. Heidecke and Heckelei (2010) extended the model to include reservoir inflows as a random variable. They estimate gamma distribution parameters of water inflows and conduct Monte Carlo experiments with random draws from the estimated inflow distributions. In this paper we compare the historical inflow distribution estimated from climate data from 1960 to 2000 with the A1B scenario of the IPCC based on REMO model data from 2001 to 2050. The first moment of the historical gamma distribution is 567, for scenario A1B 206, respectively. As this presents the average of inflows, it gets obvious that water is very scarce in the climate change scenario A1B compared to the current distribution of water inflows.

Water requirements per month and salt tolerances are crop specific. The salinity of irrigation water is determined endogenously in the model by the initial salt content in surface and groundwater, the average salinity rates of the mix of groundwater and surface water applied on the fields and the amount of water and salt leached due to irrigation (see also Heidecke and Kuhn, 2007). In general, groundwater quality in the Middle Drâa valley is more deteriorated due to the geological characteristics in the Drâa valley (Klose et al. 2008).

The simulations in this paper are made by respecting for water quality affects, in contrast to simulations which leave out water quality aspects to be able to compare ceteris paribus solely the affect of water quality regarding management options.

Water pricing is one option to manage water more sustainable. The current costs of groundwater use in the Drâa valley consist of costs for fuel and gas, and maintenance of the motor pumps. These costs have been estimated by Heidecke et al. (2008) at 58 cents of Moroccan Dirham (MAD) per cubic meter. In this paper we analyse different groundwater pricing options for the historical inflow distribution as well as for climate change scenario A1B. We first assume that an additional water charge of 1 MAD is imposed on the farmer on top of the water costs for pumping. We later wary the groundwater charge up to 3 MAD to analyse the effect of the scope of a water charge. We also derive groundwater demand functions for all oases.

Results

We compare the historical inflow distribution that was calculated on the basis of precipitation data from 1960 to 2000 with climate change scenario A1B of the IPCC from REMO model precipitation data for the years 2001 to 2050. Furthermore we compare the effects of a water pricing scheme for groundwater for different pricing options, by adding a water charge to the current costs of 58 cents MAD per cubic meter.

To address the first question, of how a water pricing scheme affects agricultural income, four scenarios are compared in Table 1. The total basin income refers to the agricultural income plus the revenues received from water pricing assuming that the charges of groundwater can be redistributed or invested in the river basin. The charge for groundwater (on top of the pumping costs of 58 cent per cubic meter) are set at 1 MAD per cubic meter (around 10 US$ cent). It is obvious that on average, agricultural income and total basin income are higher under the historical inflow distribution than under the climate change scenario A1B as overall more water is available in the river basin during the year and agricultural production is thus more efficient and productive. With a water charge of 1 MAD per cubic meter income for farmers from agricultural production is lower in both scenarios as farmers have to pay the water charge for each cubic meter of groundwater used. The total basin income, which reflects

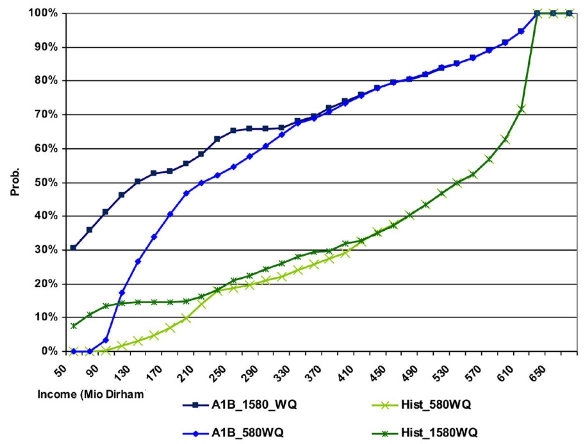
Table 1. Average values for selected indicator (and standard deviations in brackets) for the historical distribution and for one climate change scenario of the IPCC, both for the reference scenario and for the water pricing scenario

	Historical inflow distribution		A1B inflow distribution	
	No additional water charge	Water charge of 1 MAD	No additional water charge	Water charge of 1 MAD
Agricultural income	464 (166)	441(203)	277(175)	269(173)
Total income for the river basin	464(166)	466(166)	277(175)	365(125)
Surface water use	407(220)	410(218)	202 (170)	197(173)
Groundwater use	37(57)	24(40)	71(44)	86(54)

the agricultural income plus the water charge, is slightly higher in the historical scenario, and nearly 100 Million Dirham more in scenario A1B, as a lot of groundwater is used in the later and costs could be redistributed back to the farmers. Groundwater use is more expensive but therefore more efficiently distributed between the oases. In the northern oases the higher costs for groundwater use make groundwater use less profitable and more water can infiltrate to the oases downstream.

This leads to the conclusion that a water pricing scheme might even lead to higher total incomes and more effective use of groundwater in the Middle Drâa valley if water is scarce. However, a water pricing scheme that aims at water saving and at income security, the effects of a groundwater charge needs to be further investigated. Therefore,

Figure 1. Cumulative income distribution for four scenarios



we derive the cumulative income distribution function of the total basin income for the four scenarios on the basis of 1000 models runs of the inflow distribution functions in Figure 1.

The cumulative distribution of the total basin income for the four scenarios in Figure 1 reveals that with a water pricing of one Dirham per cubic meter, the distribution of income is shifted slightly to the left, which means that the probability to get lower incomes is more likely with a water price, especially in times of water scarcity as groundwater use arouses additional costs. So in case the water charge is not redirected to the farmers in monetary terms, in cases of extreme scarcity a water charge increases the probability of farmers to receive revenues of less than 200 Million Dirham.

The second question that we want to address is how water prices affect the demand for groundwater in the different oases. Therefore, several simulations with different water prices were made for the different scenarios (Figure 2). It is obvious that high salinity rates in irrigation water change the groundwater demand functions. Salinity rates are higher for groundwater than for surface water and higher

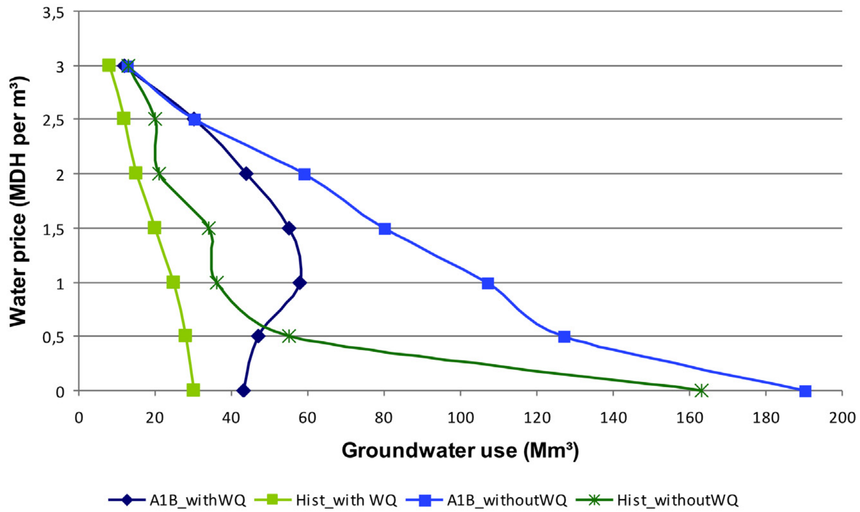


Figure 2. Groundwater demand under different scenarios

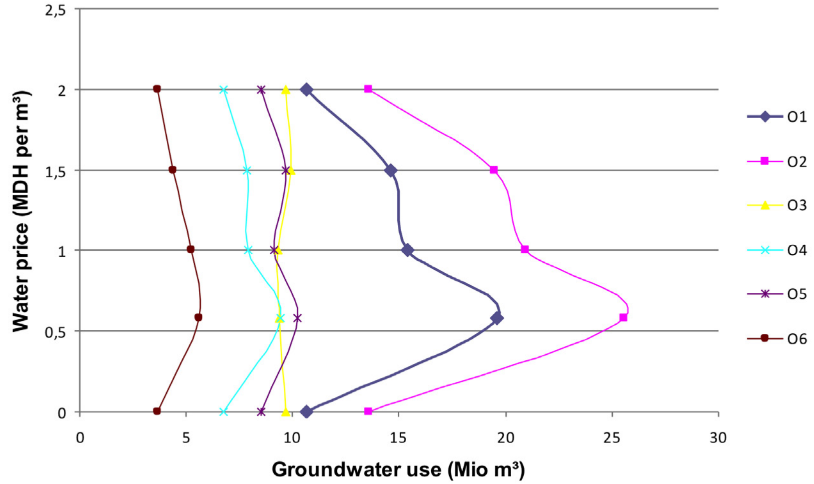


Figure 3. Groundwater demand in scenario A1B in each oases of the Middle Drâa valley

in southern oases compared to oases north upstream the Drâa river. Therefore, even with no water charge the demand of groundwater is much lower as salinity rates lead to less effective irrigation of crops.

To analyse the effect on the different oases, Figure 3 displays the different groundwater demand curves for scenario A1B´from the most northern oasis O1 to the most southern oasis O6. The northern oases closest to the reservoir have more surface water available from the river. Here, the groundwater demand curves (O1 and O2) are more elastic. However, in the more southern oases where water, especially groundwater, is scarce, the groundwater demand curves are more inelastic. This leads to the conclusion that a water pricing scheme needs to be carefully discussed taking into account the regional interactions and the demand curves of different sites. Under inelastic water demand a water pricing scheme will not lead to water conservation and will only have a negative impact on agricultural incomes.

Conclusion

Climate change impacts on water use were discussed in this paper by focusing on one case study of an arid river basin in Southern Morocco and by discussing water pricing as a management option under increasing water scarcity. We presented an optimization model which is able to consider the conjunctive use of ground- and surface water in a specific oases setting, providing the challenge that not only surface and groundwater interact, but also different groundwater bodies are connected with each other. From a methodological and an economic point of view it is of interest to see how water use in one oasis affects water use in the other oases downstream and how water pricing could be a management option for sustainable future water use, regarding the different characteristics and locations of the oases, as well as current water supply and future climate change projections.

Similar to other studies of climatic change impacts and economic valuation of water use we find that water pricing can be an option to stabilize groundwater tables and might also lead to more income given appropriate redistribution schemes of water revenues. Water pricing is less effective if water is already very scarce, either due to less water available from the reservoir, to shortages in specific oases, or water quality deterioration affecting irrigation productivity.

The limitations of this study are the following:

1. We use a comparative static setting for one year although we introduce climatic effects as a stochastic variable. Consequently, the effects between years and the availability of water depending on previous year's water use cannot be analysed.

2. A recursive dynamic simulation exercises such as Heidecke et al. (2008) allows for the analysis of groundwater tables over years. This would be interesting for future research including dynamic inter-annual salinity effects.

3. An appropriate use of the reservoir in the Middle Drâa valley is already a management option to stabilize water supply over the years. However, the reservoir is not large enough to store water over several years, so that the reservoir is more a water channel to the Middle Drâa valley from the upstream catchment area.

4. Climate change is discussed controversially and meteorologists always point out the high uncertainties related to, especially downscaled, regional data. Therefore, results related to climate change projections in this study have to be treated with caution.

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