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Adaptation strategies to climate change and climate variability: A comparative study between seven contrasting river basins

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Abstract

Adaptation strategies to climate change and climate variability to enhance food quantity and security and environmental quality and security have been explored for seven contrasting basins in the context of the ADAPT project. For the seven basins as much as possible established modeling frameworks were used, where the focus was on the linkage between field scale models to explore farm scale water management and basin scale models dealing with water resources issues. Climate change projections were scaled to local conditions where the HadCM3 and the ECHAM4 General Circulation Models as well as the seven basins required different adjustment factors in this downscaling. For the seven basins selected, impacts and adaptation strategies at field scale indicated that overall food production will increase in the future as a result of enhanced CO_2 levels, but that variation in yields will increase too. Linking this to the basin scale and including also environment focused adaptation strategies showed for the one example basin presented here, Walawe in Sri Lanka, that food security was more difficult to maintain than total food production and that environmental quality can be maintained by selecting the appropriate adaptation strategies. Results from the relatively complex modeling framework were converted to easily understandable graphs that have been used in discussions regarding adaptation strategies with various stakeholders.

Keywords: Climate change; Adaptation; Food; Environment; Modeling

1. Introduction

Pressure on food security and environmental protection will be intensified by climate change (IPCC, 2001). Strong scientific evidence indicates that the average temperature of the earth's surface is increasing due to greenhouse gas emissions. The latest IPCC (Intergovernmental Panel on Climate Change) scenarios project a global mean increase in temperature between 1.4 and 5.8 °C, and a sea level rise of 9–88 cm by 2100. Warming and precipitation would vary considerably from region to region, with effects generally being most damaging in those tropical and sub-tropical areas, which are already hot and dry.

Changes in precipitation, although more difficult to predict than changes in temperature, means a major impact on the hydrological cycle and, subsequently, on food production. It is projected that the paramount issue in changes in precipitation will be the increase in extremes rather than a long-term change in average precipitation (Kabat and Van Schaik, 2003). Adaptation measures refer to increased water storage (reservoirs, soil water, groundwater), but also to increased economic (savings/loans) and food buffer capacities. An increase in extremes includes also an increase in consecutive years of dry or wet periods, which are very difficult to overcome for poor people. A farmer might overcome

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the impact of a one-year drought followed by a normal year, but a period of two or more years of drought, even followed by a longer period of normal years, will be catastrophic to this farmer.

An international collaboration effort, involving 10 institutions across four continents, is comparing adaptation strategies among contrasting basins ranging from wet to dry and from poor to rich. Basins included are (Fig. 1): Mekong (South-East Asia), Walawe (Sri Lanka), Rhine (Western Europe), Sacramento Basin (USA), Syr Darya (Central Asia), Volta (West Africa), and Zayandeh (Iran). The project started in April 2002 and first results and preliminary conclusions are now available (Aerts and Droogers, 2004). Simulation models at basin and field scale have been set up and possible adaptation strategies have been explored by these models.

The ultimate objective of the project, referred to as ADAPT, is that outputs and especially the results of the different adaptation scenarios will have impact on stakeholders. The tools and models developed and the adaptation outputs can be used to guide stakeholders to implement adaptation strategies. This paper provides an overview of the ADAPT project results and describes the type of models used, the way stakeholders were involved and the methods used to adjust climate change scenarios for regional and field scale modeling. More details about the methodologies applied, results and conclusions can be found elsewhere (Aerts and Droogers, 2004).

2. Material and methods

2.1. A framework for adaptation strategies

The ADAPT project follows a generic methodology (Fig. 2) that quantifies food and environmentally related impacts under climate change projections. Based on these impacts, stakeholders are able to develop and evaluate different adaptation strategies to alleviate negative impacts of climate change (OECD, 1994; Aerts et al., 2003). Climate change scenarios are used as input to simulation models in order to quantify the impacts of climate change on the water resources of a river basin, and, consequently, the implications on industry, the environment and food production and security that all closely relate to the water resources system.

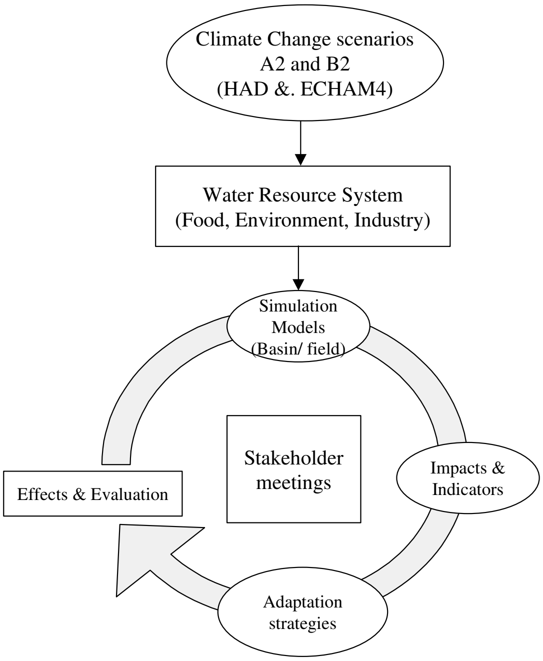

Fig. 2. The ADAPT approach.

To achieve this, it is important to define a representative set of *State indicators*, which represent the value over time of the water resources system for preserving food security and environmental quality. Hence, impacts defined are here as the change in the values of *State indicators*. Examples of such indicators for the Walawe basin in Sri Lanka are shown in Table 2. In this table four indicators as used in this study are presented:

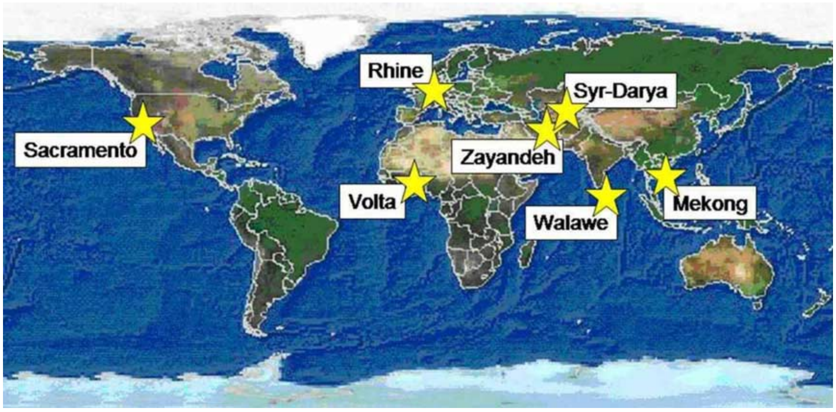

Fig. 1. The seven basins included in the ADAPT project.

- the average amount of food that is produced in a basin (kg ha^{-1}),
- the coefficient of variation in yield over a period of 30 years (%),
- the average outflow to the downstream located wetlands (m^3 y^{-1}),
- the number of years with low flow conditions over a period of 30 years (%).

The following paragraphs briefly discuss the different components of the generic approach.

2.2. Simulation models

One of the key tools used in ADAPT are simulation models running at different spatial scales (ranging from field to basin). The nature of the project design and the main interest of researchers involved from the seven basins resulted in a strong focus on basin scale activities and a somewhat less emphasize on field scale and food adaptation strategies. To ensure the application of the most appropriate model and to avoid spending substantial resources on model development, rather than on climate change adaptation strategies, we have selected existing well-tested models available in the seven basins. In basins where access to appropriate models was lacking, the water allocation model WEAP (WEAP, 2002) was used for the basin scale. The following models were used in the ADAPT project: WEAP, SWAP, WSBM (Droogers et al., 2001), SWAT (Neitsch et al., 2002), SLURP (Kite, 2000) and DPSIR (OECD, 1994). A detailed description and overview of the models used is beyond the scope of this paper, but can be found elsewhere (Aerts and Droogers, 2004).

Since most of the basin institutes did not have experience with field scale modeling, it was decided to centralize all the field scale analyzes and convey results back to the basins, where results were included in the basin scale evaluations. These field scale adaptation studies were all undertaken with the SWAP model and since this was centralized, all data sources, approaches and assumptions were similar. Details of this approach can be found elsewhere (Droogers and Van Dam, in press).

2.3. Stakeholder involvement

Stakeholder involvement was included at various levels for the different basins. For some basins, stakeholder workshops were organized (e.g. Imbulana et al., 2002), often jointly with associated projects related to water, food, climate and environment (e.g. Kabat and Van Schaik, 2003; DWFE, 2003). For other basins, stakeholder involvement was limited to a visit to farmers, water managers and/or policy makers at various hierarchical levels. Moreover, a certain level of stakeholder involvement took place at the level of the research itself because representatives from the basins did undertake the actual research. Finally, regular meetings of the key researchers from the basins strengthened this stakeholder involvement contributing to the key objective of ADAPT: comparing adaptation options between the contrasting basins.

2.4. CC scenarios

The Intergovernmental Panel on Climate Change (IPCC) provides the most recent results from seven General Circulation Models (GCM) (IPCC, 2003). We have selected two regularly used GCMs for this study: the model from the Hadley Centre for Climate Prediction and Research, referred to as HADCM3 (Gordon et al., 2000), and the one from the Max Planck Institute für Meteorologie, referred to as ECHAM4 (DKRZ, 2003).

Within the climate change projections a set of four "scenario families" exists, referred to as "storylines". We have selected to use the A2 and B2 IPCC emissions scenarios projections, the so-called SRES (Special Report on Emissions Scenarios). Each storyline describes a demographic, politico-economic, societal and technological future. Within a storyline one or more scenarios explore global energy, industry and other developments and their implications for greenhouse gas emissions and other pollutants. The storylines A2 and B2 can be summarized as follows:

- A2: A differentiated world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.
- B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.

Since the GCMs provide output at a low level spatial resolution ($2.5° \times 3.75°$ for HadCM3 and $2.8125° \times 2.8125°$ for ECHAM4) downscaling to local conditions was essential. Details about the downscaling of GCM results to the seven basins are described in detail by van de Giessen (2003). For the historical data series, the East Anglia Climate Research Unit (CRU) database was used to provide data on temperature and precipitation for all seven basins over the 1961–1990 time period (New et al., 2000). This database provides a consistently interpolated global land surface climate dataset, with an average value on a $0.5° \times 0.5°$ grid for each month between 1901 and 1996.

From the various existing statistical transformations, to ensure that historical data and GCM output have similar statistical properties, we used the method described by Alcamo et al. (1997). This method is generally accepted within the global change research community (IPCC-TGCIA, 1999). For temperature, absolute changes between historical and future GCM time slices are added to measured values

$$T'_{\mathrm{GCM,fut}} = T_{\mathrm{meas}} + (\overline{T}_{\mathrm{GCM,fut}} - \overline{T}_{\mathrm{GCM,his}}) \tag{1}$$

in which $T'_{\mathrm{GCM,fut}}$ is the transformed future temperature, T_{meas} the measured temperature for the 30 years reference period, $\overline{T}_{\mathrm{GCM,fut}}$ the average future GCM temperature and $\overline{T}_{\mathrm{GCM,his}}$ the average historical GCM temperature. The average of the transformed GCM temperature for historical times is thus the same as for measured historical temperatures. For precipitation, relative changes between historical and future GCM output are applied to measured historical values

$$P'_{\mathrm{GCM,fut}} = P_{\mathrm{meas}} * (\overline{P}_{\mathrm{GCM,fut}}/\overline{P}_{\mathrm{GCM,his}}) \tag{2}$$

in which $P'_{\mathrm{GCM,fut}}$ is the transformed future precipitation, P_{meas} the measured precipitation, $\overline{P}_{\mathrm{GCM,fut}}$ the average future GCM precipitation and $\overline{P}_{\mathrm{GCM,his}}$ the average historical GCM precipitation. More details about this approach can be found in van de Giessen (2003).

3. Results

From the wealth of information resulting from the analysis of the seven basins we have chosen to concentrate here on two specific examples: (i) inter-comparing the seven basins regarding field scale issues and (ii) Walawe Basin in Sri Lanka as en example of basin analysis across different scales.

3.1. Climate projections

As stressed earlier, adjustment of the GCM projections is essential in using these global scenarios at regional and local scales. Table 1 shows that temperature adjustment factors for HADCM3 are all below the 2 °C except for Sacramento Basin. Adjustment factors for ECHAM4 are, except for Sacramento Basin, all negative. This high adjustment for Sacramento Basin is a result of the mountain ranges included in the GCM grid enclosing Sacramento Basin, while local climate in the basin is more temperate. Adjustment factors for precipitation are large and for four out of the seven basins the GCMs projected reverse changes in precipitation. There seems to be no trend in whether a GCM is over- or underestimating a certain climatic condition (dry–wet, hot–cold) for a specific region. Also, the adjustments required for temperature do not match with the ones for precipitation. Main reason is that GCMs are energy driven and therefore less accurate and consistent in precipitation projections as these are more momentum driven.

It is most important how the GCMs perform in projections for the future. Obviously, no validation about the accuracy can be assessed and only an intercomparison is possible. Fig. 3 shows the projection for the two GCMs and the two forcings for the years 2070–2099. The overall trend is a warming world and no clear trend in precipitation.

It is remarkable that for five out of the seven basins the difference between the projections of HADCM3 and ECHAM4 is less than 1 °C. Comparing the seven basins in changes in temperature shows a tendency that wetter basins (Mekong, Rhine, Volta, Walawe) have a somewhat lower increase in temperature than the dryer ones.

Precipitation projections show a similar trend for most of the basins from the two GCMs, except for Zayandeh where HADCM3 indicates dryer conditions while ECHAM4 projects wetter ones (Fig. 3). It should be considered that Zayandeh is very dry and the difference between the two A2 scenarios is 100 mm.

3.2. Adaptation strategies

For the basins considered in ADAPT we have selected to explore adaptation strategies with four different foci: (i) business as usual, (ii) food focused, (iii) environment focused, and (iv) industry focused. The

Table 1
Adjustment factors required to scale the GCM precipitation (Prec) and mean temperature (Temp) to local conditions

	Had-A2		Had-B2		Ech-A2		Ech-B2	
	Prec (%)	Temp (°C)	Prec (%)	Temp (°C)	Prec (%)	Temp (°C)	Prec (%)	Temp (°C)
Mekong	10	−0.6	10	−0.6	−2	−1.1	6	−1.0
Rhine	−4	1.3	−4	1.2	−8	−2.0	−7	−1.8
Sacramento	−28	9.2	−29	9.2	−8	3.5	−19	3.6
SyrDarya	22	1.3	23	1.4	−15	−5.9	−2	−6.8
Volta	−32	0.8	−32	0.8	−37	−0.5	−36	−0.5
Walawe	−31	−1.1	−32	−1.1	21	−2.5	40	−2.4
Zayandeh	−41	0.1	−39	0.1	41	−5.0	32	−4.8

Had is HADCM3 and Ech is ECHAM4; A2 and B2 are the two SRES forcings.

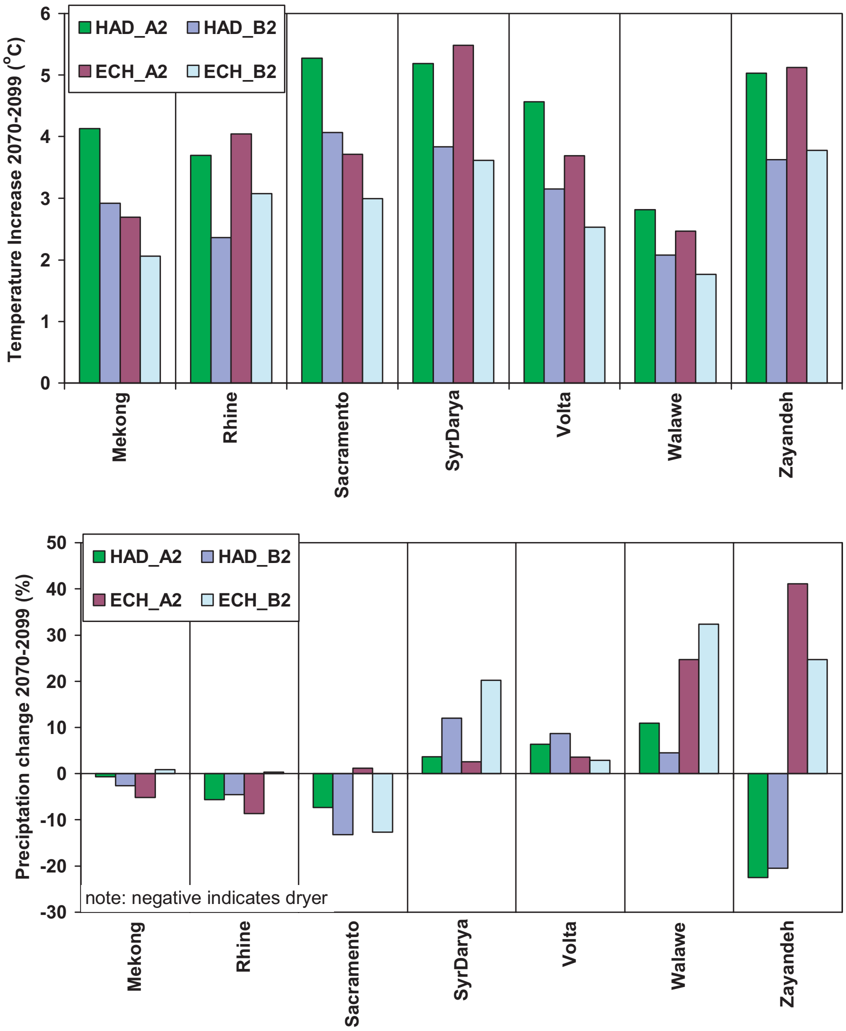

Fig. 3. Projections for the period 2070–2099 as compared to the base line (1961–1990). Note that temperatures (top) are expressed as absolute changes, while precipitation (bottom) as percentages.

latter focus has not yet been fully explored for Walawe Basin and this publication will concentrate therefore on the first three. Results are presented for the period 2010–2039. Again, results are based on the well-tested and validated linked WSBM basin and SWAP field scale models.

The most relevant adaptation strategies to climate change are related to the cropped area and the amount of water applied for irrigation. In Table 2 we have also indicated what the impact will be, if we change these two factors by 10%, where an increase can be considered as a food adaptation oriented strategy and a decrease as an environmental oriented one. Results show that under an increase of 10% in cropped area and irrigation application, the total amount of food produced will increase, but food security will go down. The environment focused adaptation strategy shows that decreasing water allocation for irrigation and

Table 2
Effects table to assess the impact of a certain adaptation strategy

	Adaptation		Indicator			
	Area (%)	Irrigation (%)	Food (% change)		Environment (% change)	
			Quantity	Security	Quantity	Security
No adaptation						
2010–2039	+0	+0	6	−10	28	−7
2070–2099	+0	+0	27	−8	78	13
Food adaptation						
2010–2039	+10	+10	19	−8	−15	−20
2070–2099	+10	+10	42	−8	28	−3
Environment adaptation						
2010–2039	−10	−10	−9	−14	85	17
2070–2099	−10	−10	10	−11	137	17

Indicator values express the change in percentage relative to the baseline period 1961–1990. See text for a further explanation of the indicators.

decreasing the cropped area will enhance environmental quantity and security.

Obviously, other percentages of changes in cropped area and irrigation depth can be explored as well using the modeling framework. Fig. 6 shows the result of these evaluations where we have put emphasize on presenting the results in a user-friendly way comprehensible to water managers and policy makers.

3.3. Field scale results

Regarding the field scale inter-comparisons, one of the most striking conclusions is that the overall picture of the impact of climate change on crop yields is positive (Fig. 4). In the business as usual option, expected yields are higher for all basins except one basin-crop combination (two for the distant-future) as can bee seen from Fig. 4. However, there is more water will be consumed (Fig. 5), and, especially for the end of this century, this increase is expected to be substantially.

Table 2 indicates that total food production in the basin, expressed in annual ton rice produced, will increase under the business as usual strategy. However, variation in yield will go up in the future. For the environmental factors (quantity is defined as the long-term average outflow to the downstream wetlands, and security as the number of years where the minimum flow requirements is not met) the same pattern can be expected as for food. This can be explained by the projected increase in CO_2, which will boost crop growth,

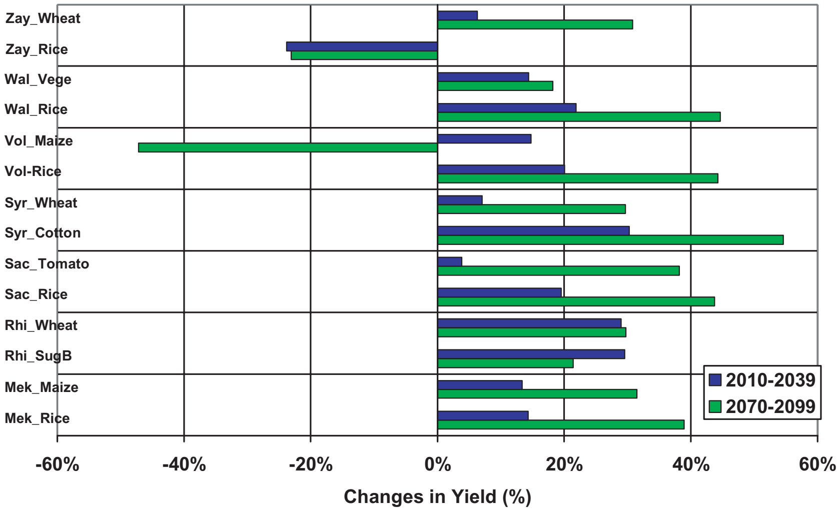

Fig. 4. Changes in yields for the periods 2010–2039 and 2070–2099 as compared to the baseline 1961–1990. Displayed are values for HADCM3 A2 climate change projections and business as usual scenario.

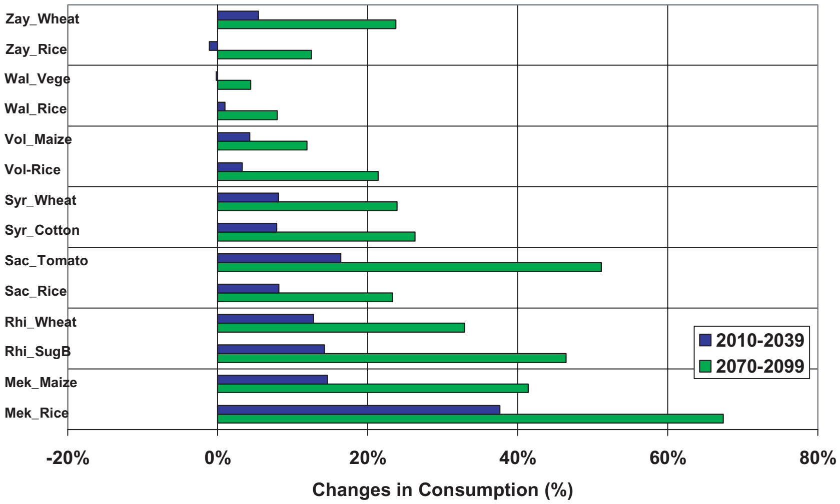

Fig. 5. Changes in water consumption for the periods 2010–2039 and 2070–2099 as compared to the baseline 1961–1990. Displayed are values for HADCM3 A2 climate change projections and business as usual scenario.

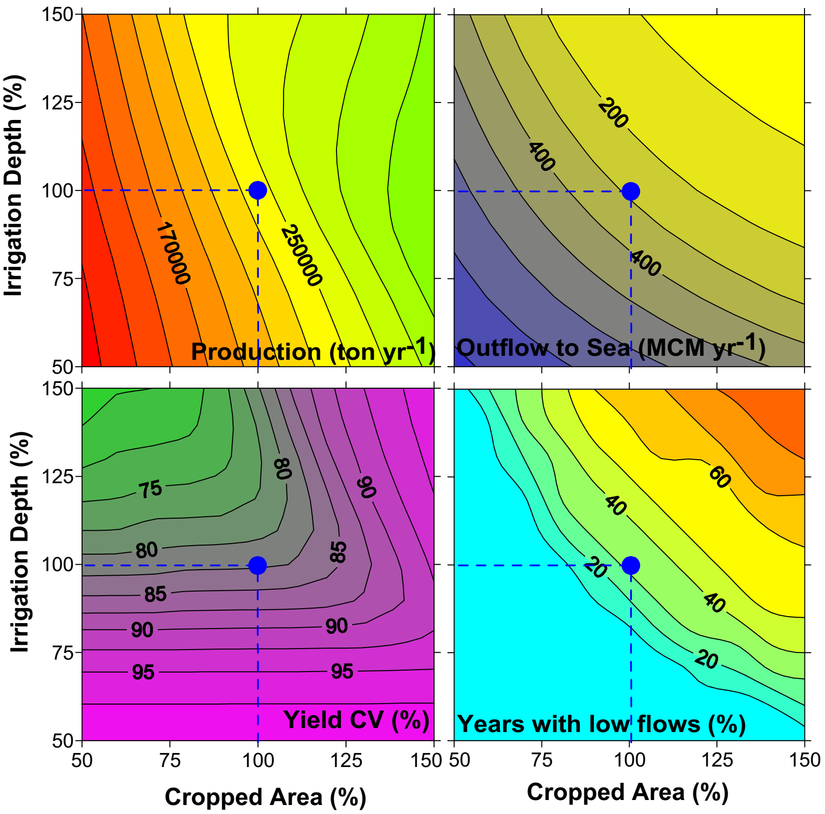

Fig. 6. Impact of adaptation strategies on food and environment quantity and security for the near-future 2010–2039. See text for a further explanation of the indicators.

and the projected increase in precipitation for Walawe. However, the increase in extremes makes that the food and environmental security goes down.

4. Conclusions

The study was based on a couple of important approaches: (i) use of existing climate change projections, (ii) adjustments of projections to local conditions, (iii) use of a simplified modeling approach for water allocation and (iv) a comprehensive model for field scale water and crop processes. This approach is powerful in analyzing impact of climate change and evaluating adaptation strategies in a reasonable short timeframe. Policy makers can use the tools presented here to help them make sound decisions regarding water policy issues. They can select as set priority (i) total food production, (ii) year-to-year variation in food production, or (iii) environmental quality. Results presented in the summary graph (Fig. 6) can be used to assess the benefits and consequences of different adaptation strategies for the priority selected on the other indicators.

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