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Designing a Land and Water Management DSS for the Tarim Basin, P.R. China

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ABSTRACT

Overexploitation of scarce water resources for irrigation agriculture is a key problem impeding a sustainable development in the extremely arid Tarim Basin in China's Xinjiang province. Therefore the SuMaRiO (Sustainable Management of River Oases along the Tarim River) project develops a Decision Support System (DSS) for integrated land and water resource management. To ensure credibility, relevance and acceptance of the DSS an inter- and transdisciplinary research approach is applied that includes local stakeholders' knowledge, perception, and preferences from the beginning of the project. The DSS-sub-models which are linked within the DSS include hydrological models (WASA, SWIM, and MIKE BASIN), quantifying discharge and irrigation water availability, bio-geophysical models (EPIC, APSIM), determining crop yields and actual crop water use, and farm optimization models (Linear programming), deciding farmers' current and future cropping pattern. Furthermore the response of riparian forests along the river, on changes in groundwater level and flooding events is determined by self-developed empirical models. The actual land and water management measures that can be simulated through the DSS comprise improvement of water transmission and storage infrastructure, restriction of agricultural land expansion, improvement of agricultural extension service, subsidization of advanced irrigation technology and others. Specific ecosystem service (ESS) indicators enable the DSS-user to judge the impact of potential water and land resource management measures under a range of future climate and consecutive river discharge scenarios. Socio-economic scenarios define future developments of agricultural input and output prices, which directly enter the farm optimization model. The ESS indicators are then determined for

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every sub-region annually until 2030 and include among others the status of natural riparian ecosystems, farmers' income, production amount of food, feed and fiber, as well as ground and surface water status.

Keywords: Decision support system, water resource management, transdisciplinary research, China

1. INTRODUCTION

1.1 Study Region

The Tarim River Basin is located in the southern part of China's northwestern Xinjiang Uighur Autonomous Region. The major part of the Basin is determined by the Taklimakan desert, the world's second largest sand desert, where annual precipitation hardly exceeds 50 mm (NCDC, 2013). Only at the edges of the basin, which are nourished by the water, provided through snow and glacier melt from the surrounding massive mountain ranges, human settlements and vital natural riparian ecosystems can exist. The 1300 km long Tarim River, constituting China's longest inland river, stretches along the northern edge of the Taklimakan desert, and provides water to the majority of the basins population (Shen, 2009).

Figure 1. Administrative map of the study region "Tarim River Basin" and the location of Aksu and Tarim River.

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From 1964 until 2011 the local population more than tripled (XJSYB, 2012), which put enormous pressure on natural resources, especially scarce water resources. Domestic and industrial water use competes directly with water demand for irrigation agriculture, which experienced a tremendous increase in the past. The total area of agricultural production in the four administrative regions of the Tarim River Basin (Aksu, Bayangol, Division 1 and Division 2) increased from 0.6 million ha in 1989 to nearly 1.5 million ha in 2011. The major agricultural commodities are cotton and fruits, while the latter experience a rapid increase in the last decade (XJSYB & BTSYB 1990-2012).

As a consequence of increased water abstraction for human purposes, groundwater tables along the river are depleting and the river bed in the lower reaches of the river fell dry frequently during the last decades. This not only led to an ongoing degradation of riparian ecosystems, but also caused tremendous yield losses for farmers in the middle and lower reaches of the river (Thevs, 2011). This trend is likely to exacerbate with future climate change leading to an even more incalculable river runoff and related water availability. As agriculture is still by far the most important income source for the local population it is crucial to find a balance between different water users along the river, while satisfying the water demand of natural ecosystems to at least maintain their vitality.

1.2 SuMaRiO Project

To support a more sustainable development in the region the Sino-German research project SuMaRiO (Sustainable Management of River Oasis along the Tarim River) was launched in 2011. Eleven German and numerous Chinese research institutions jointly conduct field research, field surveys and various modeling approaches in the fields of hydrology, climatology, ecology, geophysics, agriculture and others. The central question of the research project is how to manage land use, i.e. irrigation agriculture and utilization of the natural ecosystems, and water use in a the very water-scarce Tarim region, with changing water availability due to climate change, such that ecosystem services and economic benefits are maintained in the best balance for a sustainable regional development (SuMaRiO, 2011).

In the 1990s the Tarim Basin Water Resource Bureau (TBWRB) was founded to facilitate basin wide water resource management (World Bank, 2006). This should include a fair allocation of water resources among the different stakeholders along the river. However, historically established water use rights and a lack of awareness of overexploitation of water resources counteract this endeavor. To support the actual implementation of a basin wide water resource management plan it is vital to provide credible information on the outcomes of certain management measures under possible future developments to the TBWRB.

2. THE TARIM-DSS

The “Tarim-DSS” covers the timespan 2015 until 2030, and the entire 1300 km long Tarim River, which is divided into three sub-regions. The DSS as the common project output is realized through an intensive interdisciplinary cooperation among all research groups within the project. To ensure credibility, relevance and acceptance of the DSS a transdisciplinary research approach is applied that includes local stakeholders' knowledge, perception, and preferences from the beginning of the project. This is realized by frequent stakeholder workshops conducted jointly by Chinese and German project partners in the provincial capital Urumqi, or directly in the Tarim Basin in Aksu, Alar and Korla city. The joint development of the DSS together with local stakeholders aims at strengthening the ownership of the DSS by the local people, and ensures the outreach of the project far beyond the actual end of the project, which is scheduled for spring 2016.

2.1 Scenario Approach

Considering the inherent uncertainties of future developments in the target region regarding climatic developments as well as demographic and socio-economic developments a scenario approach is applied to realize a viable DSS. In that respect the developed scenarios are less targeted at predicting or forecasting the future, but rather at highlighting possible future developments, which is also proclaimed by Alcamo and Gallopin (2009) as well as Groves and Lempert (2007). Therefore the Tarim-DSS will consider a small number of diverse futures, which should fundamentally engage and confront the decision maker's view of the future. Three different types of scenarios can be combined freely within the frame of the final DSS. The climate and runoff scenarios (C-scenarios), as well as socio-economic and demographic scenarios (E-scenario) will define the external conditions, which cannot be influenced by the local decision makers. Those set the frame for the management scenarios (M-scenarios), which present possible combinations of specific future water and land resource management measures.

2.1.1 Climate and Runoff Scenarios

Four regional climate and runoff scenarios determine future temperature and precipitation. The change in precipitation, as well as effect of changing temperature on snow- and glacier-melt will lead to changes in river-discharge and water availability at the upper reaches of the Tarim River, which is determined using SWIM and WASA models. The regional climate scenarios are developed using different global emission scenarios (SRES B1, A1B, A2; RCP2.6, RCP4.5, RCP8.5), two global climate models (ECHAM5/MPI-OM, MPI-ESM-LR) and different downscaling procedures (STARS, CCLM, REMO). In that way the consortium aims at covering a wide range of uncertainty related to future regional climate. Finally four C-scenarios are selected, which differ significantly in absolute changes of precipitation, temperature and river discharge. Additionally certain scenarios might feature an intra-seasonal shift of river discharge; i.e. discharge peak occurs significantly earlier/later in the growing season. Furthermore scenarios might differ regarding their stability/fluctuations of timing and amount of water availability over the years; i.e. C-scenario A presents very stable water availability over all years of the DSS, while in C-scenario B relatively dry years occur now and again.

2.1.2 Socio-economic and Demographic Scenarios

Factors that cannot be influenced by local decision making are defined through the two E- scenarios. In an iterative process, which was realized through a series of workshops among German project partners, along with frequent consultation of local decision makers, the two socio-economic and demographic storylines “cotton boom” and “cotton decline” were developed (Tab. 1). The two storylines cover the range of possible socio-economic and demographic developments, as well as future agricultural input and output prices, which serve as input parameters for the respective DSS-sub-models.

Table 1. Major features of two storylines of socio-economic-demographic scenarios

Cotton boom	Cotton decline
Increasing cotton demand	Slight decrease of cotton demand
Supportive agricultural policy (pegged market)	Liberalized cotton (& agr. commodity market)
Strong increase cotton and medium alternative crops’ prices	Slight decrease of agricultural commodity prices
Steadily increasing population	Population maintains
Strongly increasing urbanization	Slow urbanization
Very positive economic development	Economic development slightly positive
Strong increase in domestic water demand	Slight increase of domestic water demand
Strong increase in perishable food demand	Slight increase in perishable food demand

The two storylines will be quantified through quantitative projections of historic developments in the region, and through projections of future global and Chinese agricultural commodity and agricultural input prices, which are provided by the GLUES project (GLUES, 2013).

2.1.3 Water and Land Resource Management Scenarios

Finally a series of resource management scenarios will be developed together with local stakeholders and decision-makers. Each management scenario has a specific focus or theme and displays logical and consistent combinations of land and water resource management measures in the region. Possible M-scenario theme might be: “Local profit”, i.e. every county tries to maximize their monetary benefit through allocating as much water as possible to their stakeholders’ regardless of downstream users, water demand of natural ecosystems and negative consequences for future generations; "Regional benefit", i.e. water resources are allocated with the goal of maximizing regional monetary output now and in the future; "Nature & Tourism", i.e. nature reserves are strongly expanded, while an intact and vital riparian ecosystem attracts tourists, which generates income alternatives for the local population.

Examples of parameters determined by the M-scenarios are as follows. Regarding water management, the scenarios define actual water allocation in space and time, the local and regional investments in water storage (reservoirs) and transmission (channels) infrastructure, as well as water pricing policy (per area, volumetric water price, water quota). With respect to land management, agricultural land expansion may be restricted or permitted, and new nature reserves may be designated. Additionally regional agricultural policy can be defined in the M-scenarios e.g. subsidization of advanced irrigation technology, subsidization for certain water saving crops, and improvement of agricultural extension service.

2.2 DSS sub-model linkages

Within the DSS a range of sub-models are linked to quantify the effects of different scenario combinations. The specific linkages and model cascade is described below.

The agricultural production is defined by the regional farm optimization model, which is strongly influenced by the E-scenarios' agricultural commodity price developments. Representative farms of each sub-region decide their cropping pattern at the beginning of the year, based on experienced agricultural input and output prices and experienced average yields of different crops. The potential yields of the prevailing crops in the region are determined by the crop growth model EPIC. In that way the hypothetical amount of irrigation water used by the farmers for optimal yield is defined. In the next step it is checked whether this irrigation demand can be satisfied with the river discharge in every sub-region through the hydrological model MIKE BASIN. After subtracting daily domestic and industrial water demand for each sub-region, irrigation water is allocated to all farms within each sub-region trying to cover crops' actual demand. The actual water availability at farm gate will depend on river discharge as well as the sub-regions' water transmission and storage capacities. Discrepancy between demand and actual supply is then quantified by MIKE BASIN on a daily basis.

In case water shortage occurs for certain crops, EPIC model determines the actual crops' yields under sub-optimal conditions. As outputs the actual crop yields are provided to the farm optimization model to assess the farms' gross margins, and actual crop water use is provided to MIKE BASIN to determine the surface water availability for downstream users, and its influence on groundwater status along the river. Finally the response of the riparian ecosystems, on changes in groundwater level and flooding events is determined by self-developed empirical models. This model cascade will be calculated for every year from 2015 until 2030.

2.3 Valuation of DSS output applying ESS concept

The future developments under specific scenario combination can finally be evaluated by the DSS-user through the display of the status of specific ecosystem service (ESS) indicators. Those are determined for every scenario combination annually until 2030. Those ESS indicators include the aesthetic value of natural and manmade ecosystems, the provision of habitats for unique plants and animal species, the provision of shelter from sand drift, soil erosion and related sandstorms, the production amount of wood, fish catch, household water supply, the production amount of food, feed and fiber, as well as farmers' income.

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