Sustainable Management of River Oases along the Tarim River (SuMaRiO) in North-Western China under Conditions of Climate Change

Christian RUMBAUR[1], Niels THEVS[2, 18], Markus DISSE[1], Michael AHLHEIM[3], Andreas BRIEDEN[4], Bernd CYFFKA[5], Doris DUETHMANN[6], Til FEIKE[7], Oliver FRÖR[4], Philipp GÄRTNER[9], Ümüt HALIK[5], Joachim HILL[10], Marie HINNENTHAL[4], Patrick KEILHOLZ[1], Birgit KLEINSCHMIT[9], Valentina KRYSANOVA[11], Martin KUBA[5], Sebastian MADER[10], Christoph MENZ[11], Hussein OTHMANLI[3], Sonna PELZ[3], Matthias SCHROEDER[6], Tuck Fatt SIEW[12], Vivien STENDER[6], Karl STAHR[3], Frank M. THOMAS[10], Martin WELP[13], Michel WORTMANN[10], Xiaoning ZHAO[3], Xi CHEN[14], Tong JIANG[15], Jing LUO[16], Hamid YIMIT[17], Ruide YU[13], Ximing ZHANG[14], Chengyi ZHAO[14]

[1]Technical University Munich, Munich, Germany, [2]Ernst-Moritz-Arndt-University of Greifswald, Greifswald, Germany, [3]University of Hohenheim, Hohenheim, Germany, [4]Universitaet der Bundeswehr Muenchen, Munich, [5]Katholic University of Eichstätt-Ingolstadt, Eichstätt, Germany, Germany, [6]GFZ German Research Centre for Geosciences, Potsdam, Germany, [7]Federal Research Centre for Cultivated Plants, Kleinmachnow, Germany, [8]Universität Landau, [9]Technical University Berlin, Berlin, Germany, [10]University of Trier, Trier, Germany, [11]Potsdam Institute for Climate Impact Research, Potsdam, Germany, [12]Johann-Wolfgang Goethe University of Frankfurt, Germany, [13]Eberswalde University for Sustainable Development, Eberswalde, Germany, [14]Xinjiang Institute of Geography and Ecology, Chinese Academy of Sciences, [15]National Climate Center, Beijing, [16]Research Center for China's Borderland History and Geography, Chinese Academy of Social Sciences, Beijing , [17]Xinjiang Normal University, [18]World Agroforestry Center, Bishkek, Kyrgyzstan

Corresponding to: Christian RUMBAUR, christian.rumbaur@tum.de; Niels THEVS, niels.thevs@uni-greifswald.de.

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Abstract

The Tarim River Basin, located in Xinjiang, NW China, is the largest endorheic river basin of China and one of the largest in whole Central Asia. Due to the extremely arid climate with an annual precipitation of less than 100 mm, the water supply along the Aksu and Tarim River solely depends on river water. This applies to anthropogenic activities (e.g. agriculture) as well as to the natural and semi-natural ecosystems so that both compete for water. The on-going increase in water consumption by agriculture and other human activities in this region has been enhancing the competition for water between human needs and nature. Against this background, 11 German and 6 Chinese universities and research institutes formed the consortium SuMaRiO (www.sumario.de), which aims at gaining a holistic picture of the availability of water resources in the Tarim River Basin and the impacts on anthropogenic activities and natural ecosystems caused by the water distribution within the Tarim River Basin. On the basis of the results from field studies and modeling approaches as well as suggestions by the relevant regional stakeholders, a decision support tool (DST) will be implemented that finally shall assist stakeholders in balancing the competition for water acknowledging the major external effects of water allocation to agriculture and to natural ecosystems. This consortium was formed in 2011 and is funded by the German Federal Ministry of Education and Research. After the data collection phase has been finished this year, the paper presented here brings together the results from the fields of climate modeling, cryology, hydrology, agricultural sciences, ecology, geo-informatics, and social sciences, in order to present a comprehensive understanding of the effects of different water availability schemes on anthropogenic activities and on the natural ecosystems along the Tarim River. The second objective is to present the project structure of the whole consortium, the current status of work, i.e. major new results and findings, explain the foundation of the decision support tool as a key-product of this project, and conclude with findings for application in the region. The discharge of the Aksu River, which is the major tributary to the Tarim, has been increasing over the past six decades. From 1989 to 2011, the area under agriculture more than doubled. Thereby, cotton became the major crop and there was a shift from small-scale farming to large-scale intensive farming. The ongoing increase in irrigated agricultural land leads to increased threat of salinization and soil degradation caused by increased evapotranspiration from agricultural land. Next to agricultural land, the major natural and semi-natural ecosystems are riparian (Tugai) forests, shrub vegetation, reed beds, and other grassland., as well as urban and peri-urban vegetation. Within the SuMaRiO cluster, the focus was laid on the Tugai forests, with *Populus euphratica* as the dominant tree species, because these forests belong to the most productive and species-rich natural ecosystems of the Tarim River Basin. At sites with a close distance to the groundwater, the annual stem diameter increments of *Populus euphratica* correlated with the river runoffs of the previous year. However, the natural river dynamics cease along the downstream course and, thus hamper the recruitment of *Populus euphratica*. A study on the willingness to pay for the conservation of the natural ecosystems was conducted to estimate the concern of the people in the region and in China's capital. These household surveys revealed that there is a considerable willingness to pay for conservation of the natural ecosystems with the mitigation of dust and sandstorms being considered as the most important ecosystem service. Stakeholder dialogues contributed to creating a scientific basis for a sustainable management in the future.

1. Introduction

The Tarim River Basin is located in Xinjiang, Northwest China. It is bordered by the mountain ranges of the Tian Shan in the north, Kunlun in the south, and Pamir in the west. The Taklamakan Desert dominates the basin with the Tarim River flowing along its northern rim. The Tarim River forms at Alar City through the confluence of the Yarkant River from the west, Hotan River from the south, and Aksu River from the north (Figure 2). The latter river contributes about 80% to the Tarim River's discharge.

Due to the extremely arid climate with an annual precipitation of less than 100 mm and a potential evaporation of about 2000 mm per year, the water supply along the Aksu and Tarim River solely depends on river water. This applies for anthropogenic formed ecosystems (e.g. agricultural land, urban and peri-urban vegetation) as well as for the natural ecosystems (riparian forests and vegetation) causing a competition for water between those ecosystems.

The region is inhabited since several centuries and some of the oldest oases of Asia are located in the Tarim River Basin. Since six decades the Chinese Government promotes the development of the western provinces of China. The demographic development and socio-economic change has led to a rapid change of land-use systems in the Tarim River Basin over the past decades and has substantially affected the quantity and quality of arable soil, surface water, and groundwater. These changes in soil and water affect the natural vegetation as well as the crop production (Bohnet et al., 1998, 1999, Hoppe et al., 2006).

The on-going settlement in this region enhances the competition for water between human needs and nature. Furthermore, there is a classical upstream-downstream conflict along the Tarim and its tributaries similar to other river basins of Central Asia (Chriacy-Wantrup 1985, Giese et al., 1998, cf. http://www.cawa-project.net/).

Against this background, a consortium of eleven German and six Chinese universities and research institutes formed the consortium SuMaRiO (www.sumario.de). This consortium was formed in 2011 and is funded by the German Federal Ministry of Education and Research. After the data collection phase has been finished this year, in the further course of the project we aim at compiling the results from the fields of climate modeling, cryology, hydrology, agricultural sciences, ecology, geo-informatics and social sciences, in order to present a comprehensive understanding of the effects of different water availability schemes on anthropogenic activities and on the natural ecosystems. The effects on the natural ecosystems are captured through the investigation and evaluation of their ecosystem services (MEA 2005) provided.

In the current project, agricultural land, riparian forests, urban and peri-urban vegetation are the ecosystems under study. These ecosystems are the basis for ecosystem services which contribute significantly to people's well-being (TEEB 2010, ELD 2013). The basic materials, like food, raw material for clothing, natural medicine and income of the inhabitants for viable livelihood are generated by the regional ecosystems. To meet these societal demands for life support, mainly to secure the incomes of the inhabitants of the region, people in the region shape the ecosystems to their needs. The hydrology is influenced by humans directly, by building reservoirs and canals as well as indirectly by land use changes, i.e. turning forests and shrub land into agricultural fields which leads to increased water abstraction from river and related evapotranspiration.

The existence and maintenance of the different ecosystems are substantial for the people living in the region. Ecosystems and the hydrology are closely linked to each other. In a Decision Support Tool a linkage between hydrology and ecosystem services will be build and decision makers will be able to get an integrated image of the whole region.

The first objective of this paper is to bring together the results from the fields of climate modeling, cryology, hydrology, agricultural sciences, ecology, geo-informatics, and social sciences, in order to present a comprehensive understanding of the effects of different water availability schemes on anthropogenic activities and on the natural ecosystems along the Tarim River. The second objective is to present the project structure of the whole consortium, the current status of work, i.e. major new results and findings, explain the foundation of the decision support tool as a key-product of this project, and conclude with findings for application in the region.

2. Project description and research sites

The current land and water management results in massive environmental and social problems in the region. Large areas of the agricultural soils have become unusable through salinization, the floodplain vegetation has vastly receded, and important ecosystem services such as attenuating dust and sand storms by vegetation have been severely decreased, or completely lost. The Chinese government has realized the immense ecological-economic problems and has tested some alleviating measures, e.g. ecological water transfers. What is lacking are sustainable approaches and measures considering the complete land and water management system with its ecosystem services in an integrated way and taking into account the diverse problem perceptions of the stakeholders.

The central question is how to manage land use, i.e. irrigation agriculture as the largest water consumer, and keep the balance between protection and utilization of the natural ecosystems and water use in a very water-scarce 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 development. The SuMaRiO project was set-up to contribute to solving this question. The project is embedded in the Sustainable Land Management Program of the German Federal Ministry of Education and Research with the GLUES project (Global Assessment of Land Use Dynamics, Greenhouse Gas Emissions and Ecosystem Services) as a linking partner of overall 12 global projects funded by the Sustainable Land Management Program (Eppink et al., 2012) (Figure 1).

The overall goal of SuMaRiO is to support oasis management along the Tarim River under conditions of climatic and societal changes by: 1) developing methods for analyzing ecosystem services, and integrating them into land and water management strategies of oases and riparian forests; 2) involving stakeholders in the research process to integrate their knowledge and problem perceptions into the scientific process; 3) developing tools with Chinese decision makers that demonstrate the ecological and socio-economic consequences of their decisions in a changing world; 4) introducing participatory approaches into the development of sustainable management structures; 5) jointly identifying options for optimizing economic, ecological, and societal utilities.

The SuMaRiO project is structured into five workblocks (WB): WB 1: Organization – project coordination; scenario management; stakeholder dialogue; data management; WB 2: Regional climate change and discharge of Tarim tributaries – monitoring and modeling of cryosphere; regional climate scenarios and medium-term forecast of precipitation; climate change impact on water discharge; WB 3: Sustainable water and land-use management in the Tarim Basin – water requirement and water quality on the plot scale (0.1 km^2); hydrology, salinity and biomass production on the local scale (10 km^2); upscaling to the regional scale (200 km^2); modeling of the water balance along the Tarim River (1000 km^2); WB 4: Ecosystem services and ecosystem functions along the Tarim River – in riparian ecosystems, non-irrigated land-use systems and urban and peri-urban oasis vegetation; WB 5: Multi-level socio-economic assessment of ecosystem services and implementation tools – multi-level economic system assessment; transdisciplinary assessment of ecosystem services for urban areas regarding dust and heat stress; actor-based decision support for land and water management.

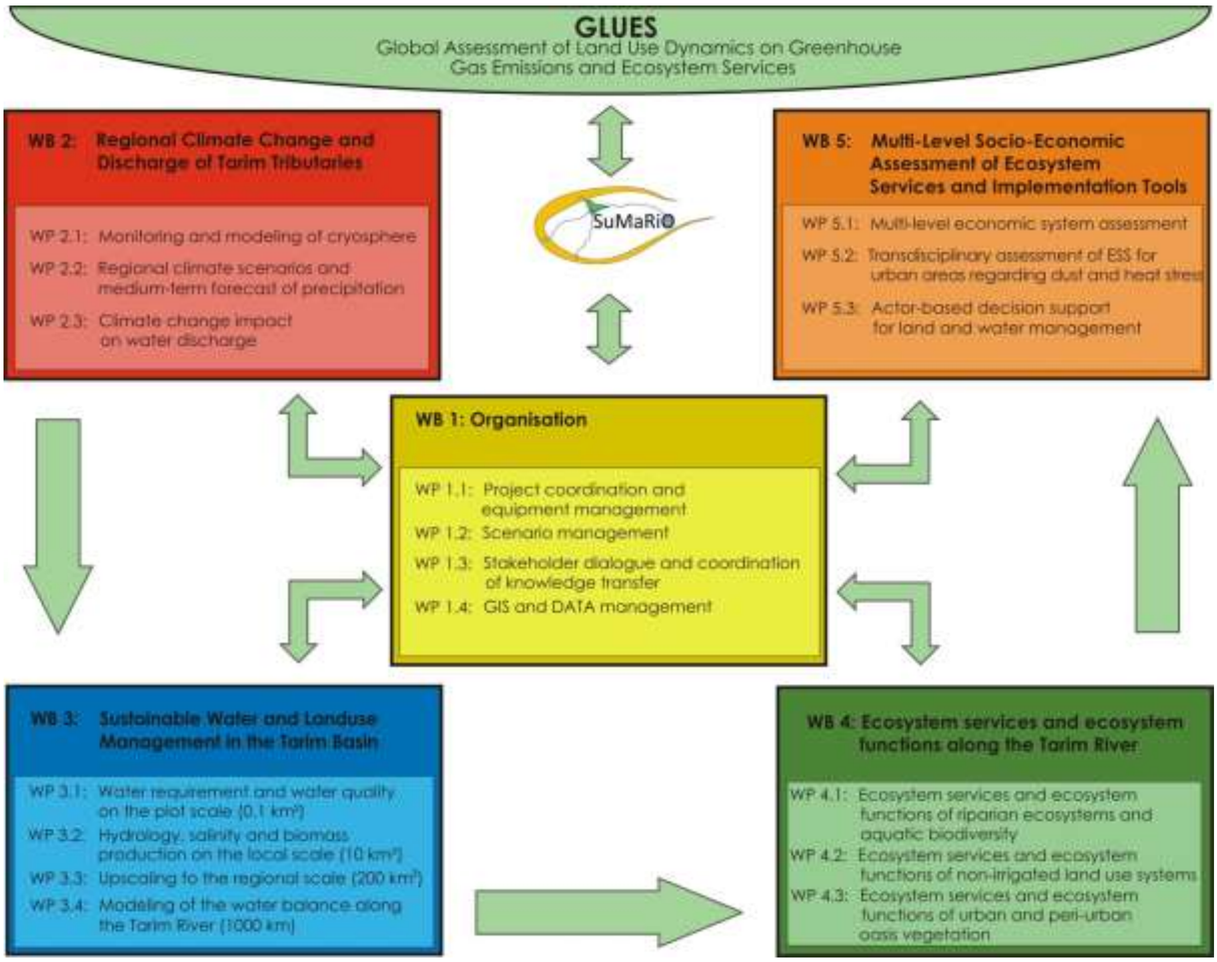

Figure 1: Structure of the SuMaRiO project. (WB = Workblocks, WP = Workpackage)

The studies of the above mentioned workblocks are carried out along the whole Tarim River including the Aksu River, in order to get an overview of a comprehensive understanding of the effects of different water availability schemes on anthropogenic activities and on the natural ecosystems along the Tarim River (Figure 2).

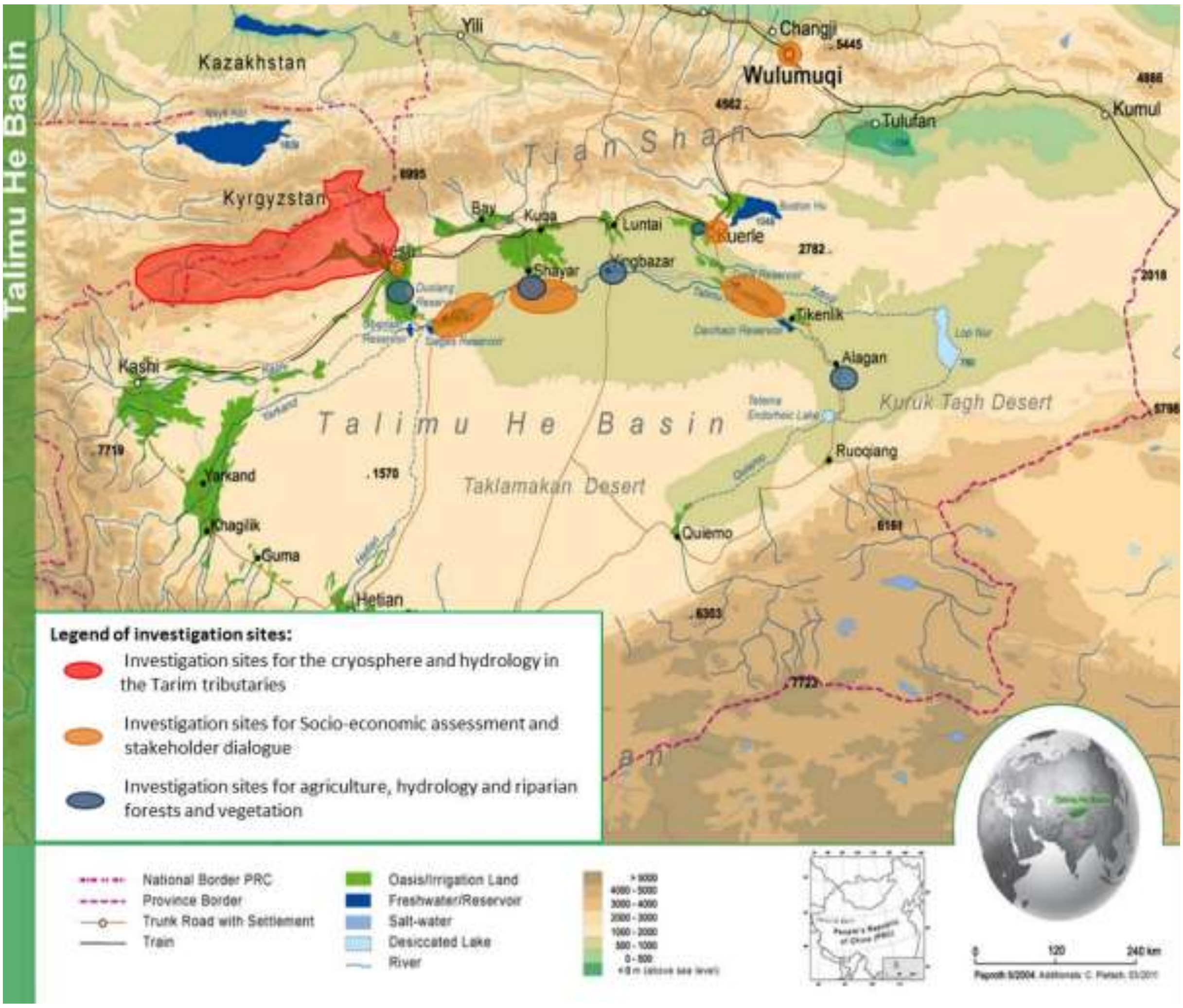

Figure 2: Map of the research area and investigation sites structured by the different scientific disciplines that contribute to SuMaRiO.

2. Methods

This paper is structured in the following way: Climate change as the regional and transregional indicator is influencing all parts of the system in the Tarim River Basin and thus standing at the beginning of the paper. The climate change part is followed by the hydrology part, as it is directly influenced by climate change. Alterations in hydrology being the life line of the region impact the agricultural land, riparian forests and urban and peri-urban vegetation. Authors are showing different results to describe the status quo of these ecosystems. In the end of the paper the economic evaluation of non-use values involving citizens in the region itself but also far away as well as the involvement of regional stakeholders (transdisciplinary research) will give a holistic view on the problem of the Tarim River Basin. An approach of supporting the problem solving of the region will be given in an outlook with a description of the project's overall result – a decision support tool.

2.1 Climate change

Climate trends were investigated in detail for the Aksu catchment, which is the most important tributary of the Tarim River, contributing 80% of water discharge to the main river. Climate data provided by the National Climate Centre, China Meteorological Administration, were used. In addition, the meteorological forcing dataset from the WATCH project that is based on ERA-40 data (Weedon et al., 2011) and the APHRODITE dataset (Yatagai et al., 2012) were used at a daily resolution. The trend analyses were performed using two methods: the linear regression and the Mann-Kendall test. For the linear regression, the slope of the regression line and the standard error were estimated, and statistical significance of the trends was calculated. The trend analysis of temperature, precipitation and river discharge was supplemented by a comprehensive correlation analysis investigating their interdependencies.

In addition, an analysis of climatic trends in the historical period for the total Tarim River Basin was done, and the results compared with those published in the literature. Due to the scarcity of observations we relied on girded datasets, namely: CRU-TS3.21 (temperature and precipitation [Harris et al., 2014]), GPCC-FD v6 (precipitation [Becker et al., 2013]) and APHRODITE_MA V1101 (precipitation, Yatagai et al., 2012). Furthermore we investigated a high resolution gridded dataset provided by the National Climate Centre, China Meteorological Administration (CMA, personal communication), which we believe has the most dense station network of all datasets, but only covers the Chinese part of the Tarim Basin. The trends were estimated using OLS-regression. Trend significance was tested using the Mann-Kendall-test.

To investigate possible future changes, we employed two regional climate models, namely the statistical climate model STARS (Werner and Gerstengarbe, 1997 and Orlowsky et al., 2008) and the dynamical climate model CCLM (Steppeler, et al., 2003 and Rockel et al., 2008). The CCLM and STARS simulations were successfully evaluated for the historical period. The simulations were compared to the results of 23 GCMs of the Coupled Model Intercomparison Project Phase 5 (CMIP5, http://cmip-pcmdi.llnl.gov/cmip5/). The regional climate models were successfully calibrated and evaluated for a historical period (see for example Wang et al., 2013). The RCP2.6, RCP4.5 and RCP8.5 emission scenarios were considered (see Meinshausen et al., 2011).

2.2 Hydrology

As precipitation is low, the Tarim Basin mainly depends on water from glacier and snow melt. The cryosphere was investigated in the western Tian Shan in the greater catchment area of the Aksu River, a tributary of the Tarim River. The Tarim River starts at the confluence of the three rivers Hotan, Yarkant, and Aksu. With a discharge contribution of about 80%, the Aksu River is the most important tributary to the Tarim River. The hydrological investigations focused on the two headwater catchments of the Aksu, the Sari-Djaz Catchment (area: 13000 km^2, 21% glacier) and the Kokshaal Catchment (area: 18400 km^2, 4% glacier), and a test site in Yingbazar at the mid-stream of the Tarim River. The runoff of the whole Aksu and Tarim River is generated in the two headwater catchments form glacier and snow melt as well as from rainfall. Downstream of those two headwater catchments, the Aksu and Tarim River behave as so-called losing streams, i.e. they drain water into the groundwater layer, but do not receive any further runoff. 80% of the annual discharge is formed during the summer season from April to September (Song et al., 2000).

First, trends in discharge during the high flow season (Apr.-Sept.) were analyzed, in order to demonstrate past discharge changes. Monthly streamflow data for the period 1957-2004 were available from Wang (2006). Second, the relation between discharge and climate variability was investigated by analyzing correlations between summer discharge and summer precipitation and temperature. Mean monthly temperature and precipitation were retrieved from the GPCC v.6 Schneider et al., (2011) and CRU 3.1 data sets Mitchell and Jones (2015), respectively. The analyses presented here are based on Krysanova (2014) and Kundzewicz et al. (2014).

In addition, a special analysis of high peaks in the river discharge time series, and interrelations between discharge and climate parameters was performed for the Aksu gauges (Krysanova et al., 2014). It is known from literature that the Aksu and Tarim rivers experience near-annually reoccurring flood events originating in the Aksu headwaters from the Merzbacher Lake due to so-called Glacier Lake Outburst Floods (GLOFs). The implications of GLOFs for downstream areas and the related challenges for the hydrological modelling and the subsequent climate impact assessment were investigated in the Aksu basin using the SWIM model. The results were published in two research articles (Wortmann et al., 2013, Krysanova et al., 2014). Some partial results demonstrating the importance of GLOFs in the region are presented below.

Third, for an 85 km^2 test site at the middle reaches (Yingbazar) the whole water cycle was modelled by the software MIKE SHE (DHI-WASY).

2.3 Agricultural land

Consuming by far the greatest amount of available fresh water resources, agriculture is the crucial factor with regard to sustainable water resource management in the Tarim River Basin. To be able to develop recommendations for a more sustainable water use in agriculture the historic developments, status quo, and improvement potentials of irrigated agriculture were determined applying a multi-disciplinary approach, including field experiments, farm survey, crop modelling and remote sensing.

Field experiments were established, in order to determine the water use efficiency of cotton cultivation under plastic mulched drip irrigation, which is the main irrigation type, on soils of different degrees of salinization. Therefore, continuous measurements of certain parameters such as soil water content, water tension, and nutrient loads of leaching water by use of TDR-tubes, tensiometers, and suction cups, respectively, were conducted during the cotton vegetation period. Measurements also included cotton yields. Afterwards, the Environmental Policy Integrated Climate (EPIC) Model was used to model cotton production in relationship to field management, soil types, and soil salinity. The results were up-scaled through a SOTER-Database of 50 soil profiles to a regional scale to generally simulate the agricultural land use. These field experiments were established 1) in the upper reaches of the Tarim River Basin (Aksu-Alar), 2) in the middle reaches, i.e. in Yingbazar, as well as 3) around Korla. At the three field plots, first the physical and chemical soil properties were investigated,

In addition to the simulated agricultural land use (cottonthe current land use and land use dynamics of the whole region were assessed with respect to the areas under agriculture and the current field management. The area under agriculture was assessed through remotely sensed time series of MODIS Enhanced Vegetation Index (EVI) Huete et al. (2002) data from the MOD13Q1 product (https://lpdaac.usgs.gov/products/modis_products_table/mod13q1). The MODIS instrument provides data at a regional spatial scale (250 m) and at 16-day intervals. This coverage allows a consistent observation of the phenological cycle within a year as well as land use dynamics in the course of several years. To this end, a time series of eleven years (2001-2011) was compiled for the entire Tarim River Basin, from which a set of 22 phenological descriptors was calculated for every year in the time series. These descriptors were used to characterize the different land use systems and their dynamics. There are two main objectives: firstly, to produce a map of land use systems for the most recent year in the time series, and secondly, to assess the increase in productive cropland during the entire time span. The latter problem approached by applying suitable, knowledge based thresholds to individual phenological parameters. These knowledge based thresholds were calibrated by using small samples obtained in the field or from higher resolution imagery.

Agricultural land use and water use is impacted by the demographic development and socio-economic change. In order to understand these impacts and to gain an overall view of the land use in the region, secondary production data were analyzed. These data included Statistical Yearbooks of Xinjiang (NBSCa, 1990-2012) and the Xinjiang Construction and Production Corps (NBSCb, 1990-2012), relevant policy documents (i.e. 5-year plans), and official ordinances related to land and water use. In addition, household interviews were conducted along the Aksu and Tarim Rivers. Survey sites were selected purposefully according to their location in the direct vicinity to the river, while respondents within the village were selected randomly. In total 256 farmers were interviewed with respect to their detailed crop management of the 2011 growing season using a standardized quantitative questionnaire; only farm production data of the 212 cotton producing farm households is presented in the current study.

2.4 Riparian forests

The major natural ecosystems along the Aksu and Tarim River are riparian ecosystems, which comprise riparian (Tugai) forests, shrub vegetation, reed beds, and other grassland. Within the SuMaRiO cluster the focus was set on the Tugai forests, because they contain the most productive and species-rich natural ecosystems of the study region. The Tugai forests are dominated by *Populus euphratica* with *Phragmites australis*, *Tamarix spp., Glycyrrhiza glabra*, *Alhagi sparsifolia*, and *Apocynum pictum* as main undergrowth species (Wang et al., 1996). The groundwater table, and thus finally the river runoff, which feeds the groundwater, plays a crucial role for the productivity, vitality, and ET_a of those forests (Wang et al., 1996, Thomas et al., 2006; Thevs et al., 2008a).

Within SuMaRiO, the productivity, vitality, both in relationship to the groundwater levels and the water supply to those forests, and the water consumption (ET_a) were investigated

in three plots at the middle reaches of the Tarim River, near the village of Yingbazar, in order to understand the effect of the groundwater table and runoff on productivity and vitality. The plots were located at distances of 7-11 km from each other and displayed groundwater tables between 2.0 m and 12.0 m. Each plot comprised a circular area with a radius of 50 m around a central tree.

On each plot, the position, tree height (with an ultrasonic hypsometer; Vertex IV, Haglöf, Långsele, Sweden) and stem diameter at breast height (dbh) were determined in all trees per plot. In addition, the crown projection area was measured in 20 trees per plot using a plummet connected to a sighting tube (Grube, Bispingen, Germany). From those 20 trees, two increment cores per tree were removed in a horizontal 90° angle at breast height with an increment borer (Suunto, Vantaa, Finland). Tree-ring width was analyzed using a Lintab 6 tree-ring analysis system (Rinntech, Heidelberg, Germany) and TSAP-Win Professional 4.67c software (Rinntech). From the individual tree rings and increment cores, tree-wise and plot-wise average values were computed. Plot-wise average ring widths were correlated to the river runoff of the preceding year after removing age trends of growth using standard methods (Rinn, 2003). Data on the annual runoff of the Tarim River at Yingbazar were provided by the Tarim Watershed Administration Bureau, Korla, China (Thevs et al., 2008b).

Additionally, the soil moisture and its connectivity were measured in a Tugai forest representative for the lower reaches of the Tarim nearby Arghan, in order to get a better understanding of the water support for the natural vegetation. The soil moisture has been measured using Decagon 10HS sensors (Decagon, 2014) since November 2011 in hourly intervals. Pedotransfer-functions (third degree regression) were used to describe the relationship between soil moisture content and pF values (Grashey-Jansen & Timpf, 2010; Grashey-Jansen et al., 2014). Applying this method, different sites with varying soil textures can be compared regarding the amount of plant-available water.

To estimate the connectivity between groundwater and soil moisture cross correlations between the two time-series were calculated. This indicates how long it took until the rising groundwater level has an effect on soil moisture in different layers.

Data on the vitality of the Tugai forests were collected in May 2013 at the same site in Arghan, because here we find the whole range of vitalities. At each soil moisture logger the surrounding *Populus euphratica* trees were surveyed using a classification scheme of six vitality classes (1 = "very good condition" to 6 = "dead"). The ranking was based on the visual impression of leaf density. Specimen of *Populus euphratica* that are in a good vitality condition will develop a higher density of leaves than those trees that suffer e.g. from water-scarcity and therefore are in a poorer condition.

The field assessment of the *Populus euphratica* was complemented by a satellite image survey, in which changes of the tree crown areas between 2005 and 2011 were assessed. The two times were chosen, in order to detect the response of *Populus euphratica* to restoration efforts in the lower reaches of the Tarim River. Thereby, an object based tree crown change detection method on two very high resolution satellite imageries from 2005 (QuickBird (QB)) and 2011 (WorldView2 (WV2)) was applied. A pixel based minimum/maximum filter was applied on derived Normalized Difference Vegetation Index (NDVI) values in order to identify crown peaks and delineated the extracted peaks into individual tree crown objects using the region growing approach (Gärtner et al., 2014).

Finally, the water consumption of the natural ecosystem (ET_a) was assessed. ET_a of the natural ecosystems along the Aksu and Tarim River was mapped from MODIS satellite images for the years 2009, 2010, and 2011 (Thevs et al., 2013; 2014). The ET_a was mapped after the S-SEBI approach as developed and described in detail by Roerink et al. (2000) and Sobrino et al. (2005; 2007) and as reviewed by Gowda et al. (2007; 2008). The following MODIS satellite data products were used, in order to cover the whole Aksu-Tarim River Basin: 8-day land surface temperature (MOD11A2), 16-day albedo (MCD43A3), and 16-day NDVI (MOD13A1). ET_a was mapped from April 1st to Oct 31st of each year, because this time span corresponds with the growing season of the natural vegetation (Thevs et al., 2014).

Additionally, one climate station was operated at a *Populus euphratica* forest from 2009, in order to calculate ET_a (Thevs et al., 2014). ET_a was calculated with the Bowen Ratio method (Malek and Bingham 1993).

Afterwards, the ET_a values for the following vegetation types were retrieved: wetlands, dense forests, forests, shrub, sparse woodland, and *Apocynum pictum* stands. The definition is given in the header of Table 5 in the result section. The ET_a values of those different vegetation types were retrieved from MODIS pixels which represented the vegetation types. Those MODIS pixels were located with the help of two Quickbird satellite images, from which forests and shrub were detected and through field investigations from which the *A. pictum* stands were localized.

2.5 Economic valuation of environmental change

The overall goal of this interdisciplinary project is to optimize the land and water management and thus contribute to a sustainable implementation strategy in the region. This includes different water distribution and land use schemes along the Tarim River which have different effects on the local natural ecosystems. Efficiency in the water management and land use strategies are expected to lead to environmental improvements in the region. The question is, whether the improvements are worth the costs caused by enhanced measures like more efficient irrigation technologies. While the costs of an environmental project can be determined rather straightforwardly on the basis of market prices like wages, capital costs and material costs, the assessment of the benefits of improved environmental conditions is more complex. There are no market prices available for ‘goods’ like wildlife, landscape beauty, improved air quality, etc. Therefore, particular valuation techniques have to be employed when determining the monetary value of a change in environmental quality.

In this study so-called direct valuation techniques were employed to assess the overall benefits of the preservation of the natural vegetation in the Tarim River Basin. Direct valuation techniques involve surveys, during which people are directly asked hypothetical questions concerning their willingness to pay for the environmental good in question. Since the restoration and maintenance of the natural vegetation along the Tarim River is likely to be especially beneficial for future generations which will have to deal with the adverse impacts of climate change and also because of the (presumably great) existence value of the rare desert ecosystems in the region, direct valuation techniques turn out to be most suitable for a comprehensive assessment of the benefits of new water management and land use strategies.

The so-called Contingent Valuation Method (CVM) is one of the most frequently applied direct valuation techniques (Mitchell and Carson, 1989). In CVM studies, the assessment of people's willingness to pay is based on personal interviews (face-to face or by mail) with a representative sample of all households affected by a public project. The average willingness to pay of the households in that sample is then multiplied by the number of all households affected in order to obtain a monetary expression of the overall benefits accruing from the public project to society as a whole.

2.6 Transdisciplinary research and stakeholder participation

Transdisciplinary research (TR) has been implemented in SuMaRiO to support the generation of scientific output that can be used for supporting land and water management under climate change and uncertainty in the Tarim River Basin. The focus was specifically on joint knowledge integration among scientists from multiple disciplines and stakeholders from various sectors (Siew and Döll, 2012). Knowledge on land and water management as well as ecosystem services are elicited and integrated in a TR process that comprises interviews and workshops. A combination of methods namely actor modeling, Bayesian networks, and participatory scenario development is applied for knowledge integration which includes integration of results generated by SuMaRiO subprojects.

Initially it was planned to conduct interviews individually with representatives of relevant stakeholders who should also participate in a series of five workshops (Siew et al., 2014). Their problem perceptions should be elicited and integrated in a causal network (a perception graph). However, challenges of getting stakeholders involved in the process were encountered at the beginning. Therefore, the initial TR approach was adapted by adding a stakeholder analysis and intensifying efforts on knowledge integration between German and Chinese scientists as well as among multiple disciplinary German scientists who are involved in SuMaRiO.

In November 2011 and November 2012, altogether 13 interviews were conducted with Chinese scientists coming from various disciplines. An overall perception graph of Chinese scientists was constructed. Additionally, an overall perception graph of German SuMaRiO researchers was generated. Both overall perception graphs were used as an input for discussion in the first multilevel stakeholder dialogue (MLSD). The workshop was participated by Chinese scientists who were and were not interviewed and representatives from our key stakeholder the Tarim River Basin Management Bureau (TRBMB). The overall perception graphs were updated after the first MLSD. In the second and third MLSDs, another key stakeholder, a representative of Xinjiang Water Resources Bureau (represented by the vice president), together with representatives from other governmental institutions, was also present. The updated overall perception graphs were used for further discussion in the second MLSD to obtain a shared problem perception. In the third MLSD, which was only participated by Chinese stakeholders from government institutions (including water, agriculture, nature protection, and livestock husbandry), the system description of the DSS, storylines of two scenarios, and possible land and water management measures identified from the perspective of German scientists (developed in a workshop in Germany) were presented and discussed. In addition to using oral communication, questionnaires during workshops in Xinjiang were used to allow collecting specific information even from those who did not participate in the discussion.

By adapting our TR approach and methods to suit ways of communication in the local socio-cultural and institutional setting, cross-sectoral and multidisciplinary communication and knowledge exchange was improved. Participants appreciated the format of the MLSD (including small group discussions in the form of World Café) which enabled interactive discussion. The interactive MLSDs allowed sharing of divergent perspectives on land and water management as well as the ecosystem services, while strengthening mutual understanding and learning among stakeholders and scientists.

3. Data management

Due to the interdisciplinary and international layout of the SuMaRiO project, it was necessary to establish standardized mechanism for scientific data management. The implementation of approved standards for geodata, metadata, software and interfaces were important to enable the interoperability and reusability of scientific spatial data. Our approach in this project was strongly influenced by international developments of Geoinformatics in general and Spatial Data Infrastructures (SDI) in particular. A number of SDIs were currently built on national, European and global level, or in scientific communities. All these efforts are based on the same set of standards and best practices, describing interfaces to webservices, interoperability of data sources etc. as there would be the standardization initiative OGC among others (OGC, 2014).

In order to achieve a standardized data management, an umbrella project GLUES (Global Assessment of Land Use Dynamics, Greenhouse Gas Emissions and Ecosystem Services) was established in the context of the Sustainable Land Management funding measure, funded by the German Federal Ministry of Education and Research (BMBF). The GLUES project supports several different regional projects of the LAMA initiative (GLUES, 2014). One of these regional projects is SuMaRiO. Within the framework of GLUES a Spatial Data Infrastructure (SDI) is implemented to facilitate publishing, sharing and maintenance of distributed global and regional scientific data sets as well as model results. The GLUES SDI supports several OGC webservices like the Catalog Service Web (CSW) which enables it to harvest data from varying regional projects. Each working group within SuMaRiO is dependent on results of another working group. Due to the spatial distribution of participating institutes the data distribution was solved by using the eSciDoc infrastructure at the German Research Centre for Geosciences (GFZ) (Ulbricht et al, 2014). The metadata based data exchange platform PanMetaDocs was established and could be used by participants' collaborative (Stender et al, 2014). PanMetaDocs supports an OAI-PMH interface which enables an Open Source metadata portal like GeoNetwork to harvest the information (OAI-PMH, 2014). Subsequently this data will be harvested by the GLUES Catalog as can be seen in Figure 3. The Figure shows the architecture of this new established SuMaRiO infrastructure node in a superordinate network of the GLUES infrastructure (Schroeder and Wächter, 2012), (Schroeder et al, 2013). Furthermore, a WebGIS solution with the standard webservices Web Mapping Service (WMS) and Web Feature Service (WFS) was implemented. Both, the metadata application and the WebGIS solution are available via the Web Portal of SuMaRiO (SuMaRiO, 2014).

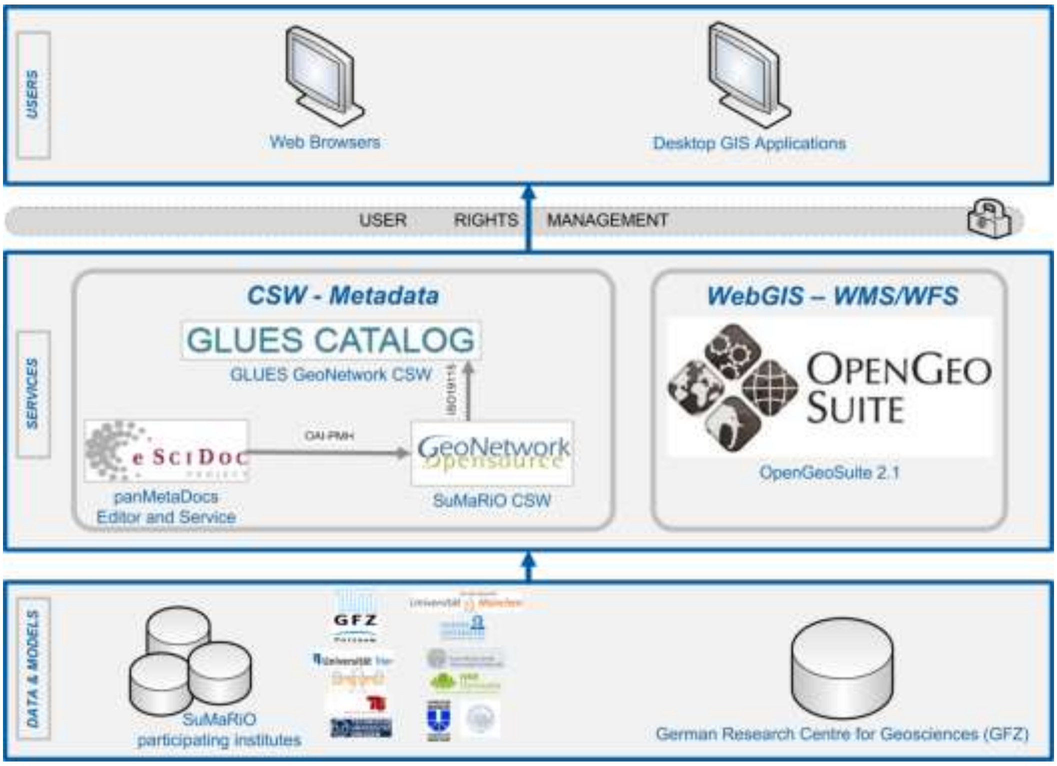

Figure 3: SuMaRiOs workflow schema of a Scientific SDI node.

The data base of the project is used for the development of an indicator-based decision support tool (DST). This tool will enable stakeholders to see the consequences of their actions in terms of water and land management under climate and socio-economic scenario assumptions. It can help to balance the economic benefits and the ecosystem services.

4. Results and Discussion

4.1 Climate change

The observations show climate change in this region. There is a general agreement that both temperature and precipitation have been increasing during the last decades in the Aksu and Tarim basins (Tao et al., 2011). According to the analysis of Shangguan et al. (2009) that is based on data from 25 weather stations in the Tarim River basin, a warming of 0.77 ± 0.16 °C (0.019 °C a^{-1}) and an increase in precipitation of 22.8 ± 7.9% between 1960 and 2000 were found for the region.

Our results on observed trends in the Aksu basin are based on data from CMA and WATCH project for the period 1961-2001. The statistically significant positive trends in temperature were found for 30 out of 40 grid points in the lower Chinese part of the drainage area, and the average increase for 30 stations was 0.017° C a^{-1} (equivalent to 0.66 ± 0.012 ° C in 40 years). All grid points without a significant trend are located in the western Chinese part of the basin. The temperature trends in the upper Kyrgyz part were statistically significant for all 10 grid points and higher than in the Chinese part: on average 0.026° C a^{-1}, or 1.027 ± 0.016 ° C in 40 years.

The positive, statistically significant trends in precipitation in the Aksu basin in 1961-2001 were found for 24/30 out of 40 grid points in the Chinese part, where CMA data was used, for the Mann-Kendall/linear model tests, respectively. The average increase for the 24 stations was 1.04 mm a^{-1}, which is equivalent to 41.5 ± 0.8 mm in 40 years. The trends are not statistically significant according to both tests for points located in the western part of the basin. The precipitation trends in the upper Kyrgyz part using APHRODITE and WATCH data were all not statistically significant. The results on the detailed analysis of climatic trends in the Aksu basin are described in two research articles (Krysanova et al., 2014, Kundzewicz et al., 2014).

In addition, we used available climatic datasets to evaluate temperature and precipitation trends in the total Tarim drainage area. A significant increase of temperature and precipitation within the period 1962-2006 was found, which is in agreement with several other studies (see, for example, Tao et al., 2011 and Chen et al., 2006). The results based on the CRU-TS3.21 and CMA datasets show a temperature increase of 0.3 K per decade. The results based on the CMA, GPCC-FD v6 and APHRODITE_MA V1101 datasets show an increase in precipitation of 6 mm per decade. All calculated trends were significant at a 5% significance level based on a Mann-Kendall test. Only CRU-TS3.21 data show an insignificant precipitation increase, possibly owing to the scarcity of the underlying station network in the Tarim Basin (Harris et al., 2014). Therefore we can confirm the observation of a shift towards a warmer and wetter climate of Shi et al. (Shi et al., 2007) on the basis of multiple datasets.

Climate scenarios were evaluated for three future periods: 2011-2040 (STARS, CCLM, CMIP5), 2041-2070 (CCLM, CMIP5) and 2071-2100 (CCLM, CMIP5). According to climate projections, the increase in temperature and precipitation will continue in the future. Comparing the near future period 2011-2040 with the baseline period 1981-2000 STARS projects a temperature change from 0,1 to 2,0 K and a precipitation change of -2 to 27 mm on the annual basis over all simulations and scenarios. CCLM shows a similar change for the near future with a temperature change of 0. 9 K for all scenarios and a precipitation increase between 11 and 35mm. The investigated GCMs show a similar change.

The precipitation increase is confined to late spring and early summer. We did not observe a statistical significant difference between the emission scenarios in the period 2011-2040. For the focus periods 2041-2070 and 2071-2100 the emission scenarios become distinguishable, with highest changes in precipitation projected for the high emission scenario RCP8:5. For the last future period 2071-2100 CCLM shows a temperature change between 0.8 and 4.5 K, and a precipitation change of up to 38 mm compared to the baseline conditions. Furthermore, CCLM and the CMIP5 GCMs show a precipitation increase for the winter season in the mid and last projection period. However, the overall change in all months is small (below 15 mm) for all periods and scenarios. Also it can be indicated that the range in the change signal of the CMIP5 models is considerably higher than others for all scenarios and is growing with time. Some GCMs show a decrease of up to 49 mm in annual precipitation.

4.2 Hydrology

The trend analyses showed significant increases in the summer discharge ($p<0.01$) of the Aksu headwater catchments over the time span 1957-2004. Discharge increased by 152 mm y^{-1}, or 23% relative to the mean flow over this period in the Sari-Djaz Catchment, while discharge in the Kokshaal Catchment showed a lower change in absolute terms with 88 mm y^{-1}, but a stronger increase in relative terms with 35% (Figure 4). However, the discharge did not increase in a uniform way over the whole period. The increase was particularly pronounced during the last decade. A period with relatively high discharge was also observed in the mid to end 1960s, while discharge values were rather low in the 1980s.

Correlation analyses of discharge and temperature/precipitation during the summer half year revealed a positive correlation of discharge with temperature for the highly glaciated Sari-Djaz Catchment (Spearman’s rho=0.63, $p<0.01$), while there was no significant correlation with precipitation. In contrast, in the Kokshaal Catchment a weak but significant positive correlation to precipitation was found (Spearman’s rho=0.50, $p<0.01$), but the correlation to temperature was not significant. This is due to the different characteristics of the two headwater catchments: Temperature variations play a large role for inter-annual discharge variations in the highly glacierized Sari-Djaz Catchment, and precipitation is more important in the Kokshaal Catchment, where snowmelt and rainfall have a stronger influence on the annual discharge amount. At other time scales these relations between climate and discharge parameters can be different. For example, at the daily time scale, discharge variations are strongly correlated to temperature variations also in the Kokshaal Catchment, resulting from increased snow and glacier melt on warmer days (Krysanova et al., 2014).

An analysis of high peaks in river discharge, and interrelations between river discharge and climate parameters was performed for the headwater catchments of the Aksu, focusing on the Xiehela station on the Kumarik River (see details in Krysanova et al., 2014). The annually reoccurring Glacial Lake Outburst Floods (GLOF) of the Merzbacher Lake, located in the Kyrghiz headwaters of the Aksu River cause the discharge records to peak at the Xiehela station in late summer - autumn (end of August – October). This unique hydrological event has had a significant impact on the discharge of the Aksu and Tarim Rivers in the past (Glazirin, 2010; Wortmann et al. 2013), and has shown a high volatility in terms of occurrence, peak discharge and flood volumes. Although it is an erratic event, the occurrences show a high dependence on local weather as well as the dynamics of the damming Enylchek glacier (Ng et al. 2007). Wortmann et al. (2013) analysed GLOFs by means of hydrological modelling with the SWIM model and using discharge records from the Chinese gauging station Xiehela, located some 200 km downstream of the Lake. They were able to prove the occurrence of GLOFs in the discharge time series (see example in fig. 4), and provided reliable flood volume estimations of between 100 and 250 Mil. m^3 per event, accounting for 3 to 6 % of the total annual discharge at the Xiehela station.

The outburst events alter the annual discharge regime and pose a threat to infrastructures downstream, as the floods' occurrence is shifting closer to the melt water peak, *i.e.* leading to increased peak discharges in late summer. The construction of reservoirs immediately upstream of the Xiehela gauging station located some 200 km downstream of the Lake has increased the importance of flood volume and peak discharge estimates and predictions. The Xiaoshixia Reservoir has been operational since 2012 with a maximum capacity of 69 Mil. m^3, and the second, much large Dashixia reservoir is planned to be operational by 2019 with a maximum capacity of *ca*. 1274 Mil. m^3. Including these events in the planning of the reservoir construction, in climate impact assessments and management plans is a challenge for hydrological modellers and decision makers.

In a next step, possible impacts of climate change on water availability will be investigated using a scenario approach, i.e. climate scenarios are applied as input to hydrological models. In such highly glacierized mountain catchments this approach has particular requirements. A robust parameterization is important, considering that errors in simulated glacier melt may be compensated by precipitation errors. This may be achieved with a multiobjective calibration. The model also needs to take account of dynamic changes of the glacier area, either by incorporating externally generated future glacier area scenarios, or by simulating glacier area changes. The ability to represent the discharge changes observed in the past can be an important check for the applied hydrological models.

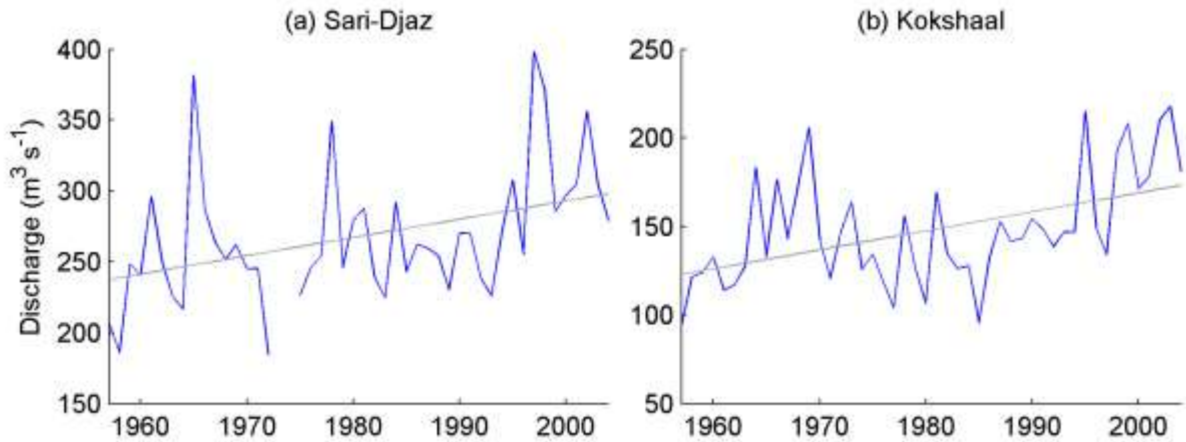

Figure 4: Average discharge for the summer season (Apr-Sept) for two headwater catchments of the Aksu River. (a) Sari-Djaz Catchment; (b) Kokshaal Catchment. Observations are shown in blue, and the estimated trend line in gray.

The Increasing discharge from the Aksu headwaters results in more water resources available along the Aksu and Tarim River so that the expansion of agricultural areas becomes more attractive.

The modeling of the whole water cycle at Yingbazar showed that in the year 2012 an amount of 114 mm/a (98 %) of the groundwater recharge was contributed by the natural annual summer flood. The groundwater recharge is that amount of water which is stored in the aquifer after evapotranspiration and infiltration losses. Meanwhile dykes have been built along nearly the whole upper and middle reaches, except for Yingbazar. Though, there are locks at major river branches so that they may receive water from the Tarim River. If dams were build in Yingbazar, too, and the floods only entered through such a lock, the groundwater recharge by the flood would drop to 41 mm/a (62 %) (Figure 5) (Keilholz, 2014).

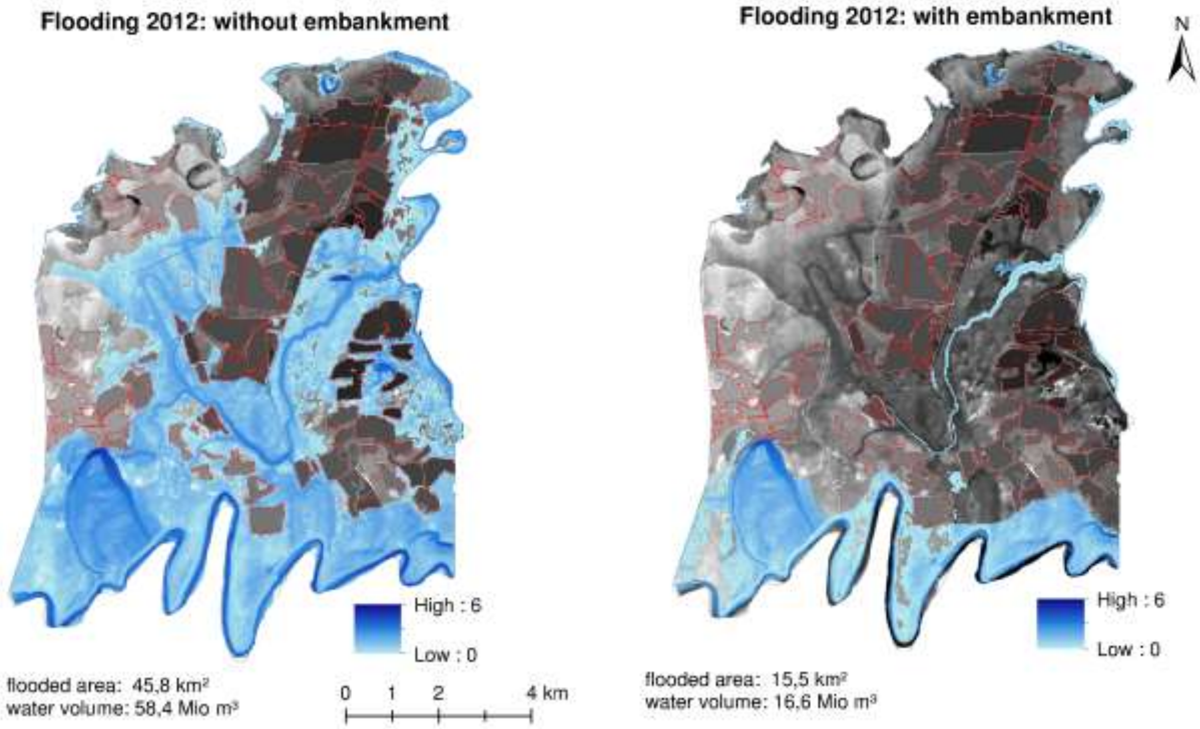

Figure 5: Different modeled flooding scenarios without (right) and with embankment (left) along the Tarim River using the discharge volume of the flood of 2012.

4.3 Agricultural land

Over the last three decades, the land use area extremely expanded along the Tarim River. The total agricultural land use area more than doubled from 1989 to 2011. In recent years, cotton and tree fruits are the main agricultural commodities (Figure 6).

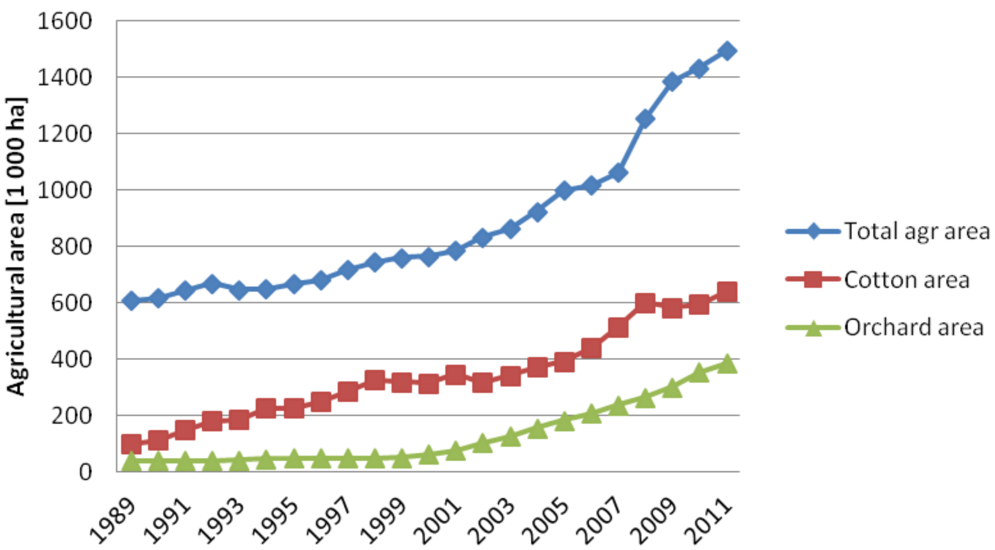

Figure 6: Development of total agricultural land use area, as well as cotton and orchard area in the Tarim Region in the last two decades (calculated from NBSCa 1990–2012 and NBSCb 1990–2012).

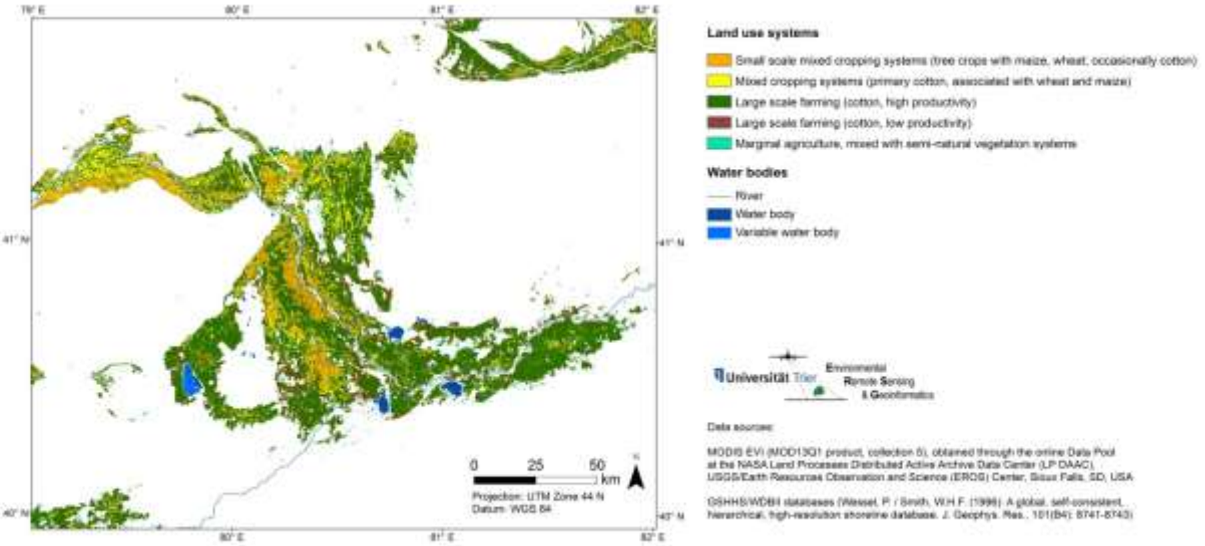

Figure 7: A map of land use systems for the Aksu oasis in 2011.

The agricultural land use trends observed in the official statistics are confirmed by the MODIS data analysis, with the largest increase of cropland occurred between 2004 and 2008. The most rapid changes were observed in Aksu and Korla, where there was an expansion of cotton production in state operated farms of the Xinjiang Construction and Production Corps at the fringes of the large oases located in these districts. In Aksu, it was estimated that the area of productive cropland increased by more than 300 km^2 every four years.

The MODIS time series showed that the area of productive cropland increased from about 18,000 km^2 in 2001 to about 25,000 km^2 in 2011 for the Tarim River Basin, including the Aksu River Basin. Thereby, large scale highly productive cotton monoculture, less productive cotton systems, and small scale Uyghur cropping systems and marginal agriculture mixed with semi-natural vegetation covered 11,000 km^2, 4000 km^2, and 10,000 km^2, respectively. The existence of low productive and marginal mixed crop land indicates that actual crop water requirements can no longer be fully satisfied for the vast expanding crop land. The traditional Uyghur land use system is characterized by fields in rather small parcels of land with permanent tree cultures (e.g. walnut or fruit trees) in combination with a rotation of crops, most frequently maize and winter wheat, planted under the trees. Cotton, on the other hand is typically grown in intensive monocultures since it requires a fair light intensity to grow. Figure 7 shows the distribution of those land use systems for the Aksu River Basin and the Tarim upper reaches as an example.

Apart from the steady increase in population and related agricultural labour force, the very good producer price developments for cotton and especially tree fruits obviously drive the reclamation of crop land (Figure 8).

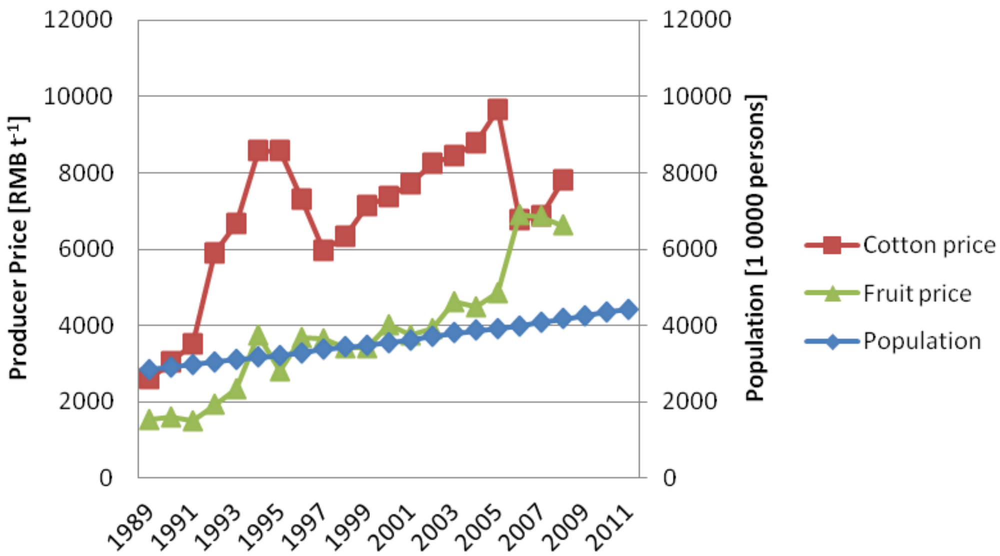

Figure 8: Development of Producer Prices of the major agricultural commodities cotton and tree fruits, as well as population development in the Tarim Region in the last two decades (calculated from NBSCa, 1990–2012 and NBSCb, 1990–2012; FAOSTAT, 2012).

The insufficient control in the field of land reclamation supported the agricultural land expansion. This resulted in an increased water demand by the agricultural sector. The local governments have realized the urgency of the problem situation aiming for a stabilization of agricultural land, while shifting agricultural labour force into other sectors of industry (Feike, et al. 2014). Increased investments into agricultural extension services seem a viable option, in order to improve farmers' management and water use efficiency and thus reduce agricultural water consumption, while the sole increase of water price for farmers may have no positive effect with regard to a reduction of the water consumption (Mamitimin et al., 2014).

The massive increase in irrigation agriculture in the Tarim River Basin caused reduced river runoff and increased evaporation from agricultural land (Yao et al. 2013). This led to an increase in salinity levels of soils and upper aquifers (Han et al. 2011), posing the question of the impact of increasing salinity on crop yields. Therefore field conditions were investigated.

At two experimental sites along the river, soil chemical and physical properties, soil water content, soil suction and matric suction, cotton yield and water use efficiency under plastic mulched drip irrigation in different saline soils were measured in the cotton growth season to study the influence of soil salinity on cotton yields. On the two investigation sites three soils with different degree of soil salinity were chosen: low soil salinity in Korla (17-25 mS cm^{-1}), medium soil salinity in Aksu (29-50 mS cm^{-1}) and high soil salinity in Aksu (52-62 mS cm^{-1}) over a soil profile of 100 cm. The low saline soil in Korla had the highest cotton yield (6.6 t ha^{-1}), the highest irrigation water use efficiency IWUE (0.012 t ha^{-1} mm^{-1}) and the highest water use efficiency WUE (0.001 t ha^{-1} mm^{-1}). High water content below 30 cm soil profile in high saline soil increased the risk of salinity and led to lower cotton yield (2.4 t ha^{-1}). The salinity stress for cotton was prevented by low soil matric potential (> 30 kPa) during the vegetation period in Korla and thus produced the highest yield. Compared to high saline soils in Aksu, the low saline soil in Korla saved 117 mm irrigation and 100 mm total water to reach 1 t ha^{-1} cotton yield and increased 0.005 t ha^{-1} mm^{-1} and 0.007 t ha^{-1} mm^{-1} for WUE (water use efficiency) and IWUE (irrigation water use efficiency), respectively. The collected soil salinity data was basis for the modeling of cotton yields on different soil types in Aksu-Alar region.

The EPIC model simulation under the current conditions of field management and irrigation scheme showed best estimated cotton yield on Calcic Gleysols (GLcc) with 7.78 t ha^{-1}. Gleyic Phaeozems (PHca), Gleyic Fluvisols (FLgl), Gleyic Solonchaks (SCgl) and Gypsic Solonchaks (SCgy) resulted high estimated cotton yield. The lowest estimated cotton yield was on Haplic Arenosols (ARha) and Puffic Solonchaks (SCpu) with 3.11 t ha^{-1} and 3.74 t ha^{-1}, respectively (Figure 9).

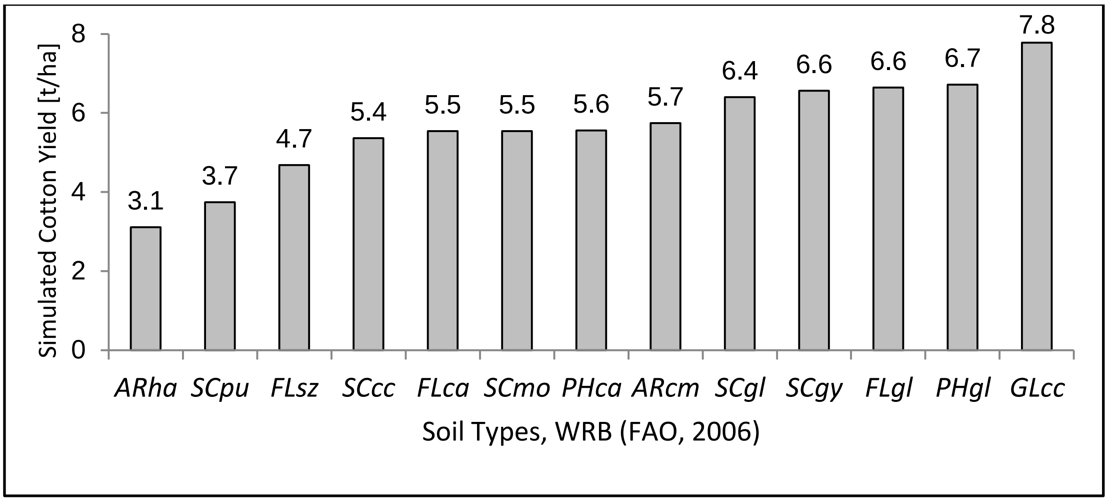

Figure 9: Average simulated cotton yield of each soil type in Aksu-Alar [*ha^{-1}].

Based on the findings, for sustainable management it can be recommended to run the cotton fields under low salinity. Comparison between low salinity and high salinity will produce 4 t ha^{-1} more yield and save 1000 m^3 ha^{-1} water per season. For the field of a farm with 100 ha it would bring additional harvest of 400 t ha^{-1} and save about 105 m^3 of water per year.

To minimize salinity induced yield losses, farmers in the region try to flush accumulated salts out of the rooting zone by flooding their fields twice a year (Shen and Lein, 2010). As reduced water availability hinders an effective control of salinity of all crop land, it is important to increase the availability of water for flushing by reducing overall agricultural water use. Therefore farmers' water consumption, as well as agronomic and economic performance of cotton production under the two prevailing irrigation techniques – drip and flood irrigation – was investigated by field survey.

Huge differences were observed between farms using drip irrigation versus flood irrigation. Table 1 displays that the total water consumption under drip irrigation is around 1500 m^3 ha^{-1} smaller compared to flood irrigation.

Table 1: Average water consumption, yield level and farmers' perceived salinity of cotton production of drip and flood irrigating farm households along the Tarim River.

Irrigation method	Number of farms	Water consumption			Yield	Salinity problems		
		Irrigation	Flushing	Total		Yes	Increase	Decrease
		[m^3 ha^{-1}]			[kg ha^{-1}]	[% of farmers]		

Drip	115	4164.3	2791.5	6955.8	5533.9	83.5	65.2	15.7
Flood	113	5391.9	3036.4	8428.2	3906.1	77.0	48.7	26.5
Total	228	4772.7	2912.9	7685.6	4727.1	80.3	57.0	21.1

At the same time the average yield obtained under drip irrigation was more than 1500 kg ha^{-1} higher than underflood irrigation. The observed yield levels under drip irrigation are in line with results from Wang et al. (2012), who reported yield levels of 5000 to 6400 kg ha^{-1} from field experiments in Xinjiang.

Around 80% of cotton farmers reported that soil salinization problems occur in their fields. Salinization problems increased in recent years for most farmers, especially under drip irrigation. This indicates that the reduced irrigation amounts under drip irrigation constitute a challenge to soil salinity management. Looking at the economic performance of cotton production (Table 2) drip irrigation entails nearly twice the variable cost for irrigation compared to flood irrigation. However, the higher yield level under drip irrigation led to an average gross margin, which was 800 US-$ ha^{-1} higher compared to flood irrigation. Fixed investment costs for the drip irrigation system were estimated between 180 and 350 US-$ ha^{-1} a^{-1} by Wang et al. (2012). Thus over the sampled farm households drip irrigation seems a viable options for cotton irrigation along Tarim River performing better in agronomic and economic terms over flood irrigation. However, flood irrigation requires fewer cost and thus capital demand by the farmers.

Table 2: Economic key figures of cotton production of drip and flood irrigating farm households along the Tarim River.

Irrigation method	Number of farms	Total variable cost	Irrigation variable cost	Revenue	Gross margin
		[US-$ ha^{-1}]			
Drip irrigation	115	5097.5	849.7	7182.4	2084.9
Flood irrigation	113	3907.1	440.1	5107.2	1200.1
Total	228	4507.5	646.7	6153.9	1646.4

To reduce water shortage induced ecosystems degradation and agricultural productivity losses it is essential to reduce agricultural water consumption. Promoting drip irrigation and restricting agricultural land use can help saving water, which thus becomes available for natural ecosystems and an effective salinity management of the remaining crop land. The results of the farm survey show that the higher yields generated by drip irrigation would allow a higher production and farm incomes even under reduced agricultural production area.

4.4 Riparian forests

In the Tugai forests in Yingbazar, tree age was lowest at the shortest groundwater distance and highest on the plot with the largest distance to the water level (Table 3). The number of trees, the stand density, basal area, tree cover and tree height all decreased with increasing distance to the water table. These differences in the stand structure were also reflected in the stem morphology: dbh was largest and the height: dbh ratio was lowest on the plot with the largest distance to the groundwater.

Table 3: Stand structure and tree morphology of the three *Populus euphratica* study plots near Yingbazar with close (GD1; 2.0 m), intermediate (GD2; 7.5 m) or large distance (GD3; 12.0 m) to the groundwater (means ± standard deviations, if applicable). Different lower-case letters indicate statistically significant differences among the plots (Kruskal-Wallis *H*-test, followed by multiple pairwise Mann-Whitney *U*-tests)

Plot	GD1	GD2	GD3
Number of trees per plot	367	297	53
Stand density (trees ha^{-1})	467	378	67
Basal area (m^2 ha^{-1})	18.7	15.7	13.3
Tree cover (%)	75	31	6
Maximum tree age (years)	68	141	314
Tree height (m)	10.6 ± 5.3 a	7.6 ± 1.8 b	5.2 ± 2.2 c
Diameter at breast height (dbh) (m)	0.20 ± 0.10 b	0.21 ± 0.08 b	0.44 ± 0.24 a
Height:dbh	55.4 ± 15.7 a	39.2 ± 12.3 b	15.5 ± 9.3 c

Minimum, average and maximum tree-ring width decreased with increasing distance to the water table (Table 4). On the plot with the closest distance to the groundwater, but not on the plots with larger groundwater distances, the standardized stem diameter increment correlated significantly with Tarim River's runoff of the preceding year for the time period of 1957 to 2005, for which runoff data were available (Figure 10).

Table 4: Minimum, average and maximum tree-ring widths of *Populus euphratica* and time period covered by tree-ring analyses in stands with small (GD1), intermediate (GD2) and large distance (GD3) to the groundwater (mean values of all available years with standard deviations). Different lower-case letters indicate statistically significant differences among the stands (Kruskal-Wallis *H*-test, followed by multiple pairwise Mann-Whitney *U*-tests)

Plot	Minimum width (µm)	Mean width (µm)	Maximum width (µm)
GD1 (1946-2011)	100	1794 ± 452 a	8865
GD2 (1862-2011)	50	1085 ± 277 b	8515
GD3 (1683-2011)	30	526 ± 207 c	2880

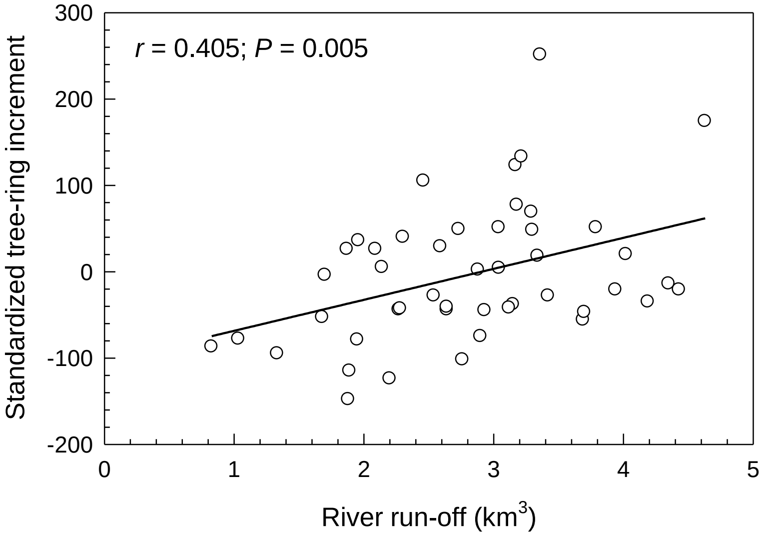

Figure 10**:** Standardized annual stem diameter increment of *Populus euphratica* trees growing on study plot GD1 at close distance (2.0 m on average) to the water table plotted against Tarim River's runoff of the preceding year at Yingbazar during the time period 1957-2005. n = 47. r, Pearson correlation coefficient

The connection between runoff of the Tarim River and the soil moisture was studied at a research site in the lower reaches. At this site the soil moisture conditions are suitable for the existing vegetation. Within all soil layers, deeper than 50 cm from the surface, the soil water content is within the plant available range during the whole measuring period (see Figure 0). Seasonal trends are not very strong and probably overlaid by effects of artificial water-releases. The effect of those water releases can best be seen in the time from September 2013 to January 2014. Immediately after the rise of the groundwater level – which is induced by increased river discharge- the mean pF-Values react. It can be seen from Figure 11 that deeper levels show an earlier increase in soil water content that shallower ones.

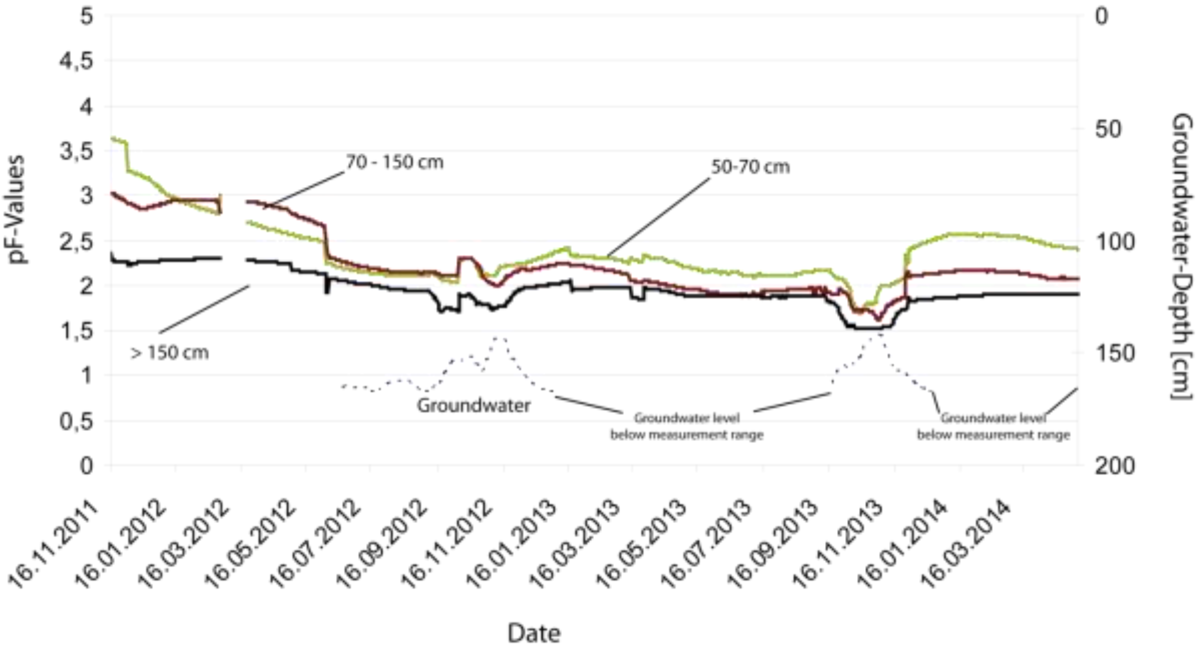

Figure 11: Mean pF-Values of all soil moisture stations for different soil layers

This effect is exemplarily shown in Figure 12. Here the cross correlation functions (ccf) for sensor 1 (-60 cm) and 3 (-150 cm) and the groundwater level are shown for the timeframe September 2013 to January 2014. The red dots mark the time lag with the highest correlation coefficient.

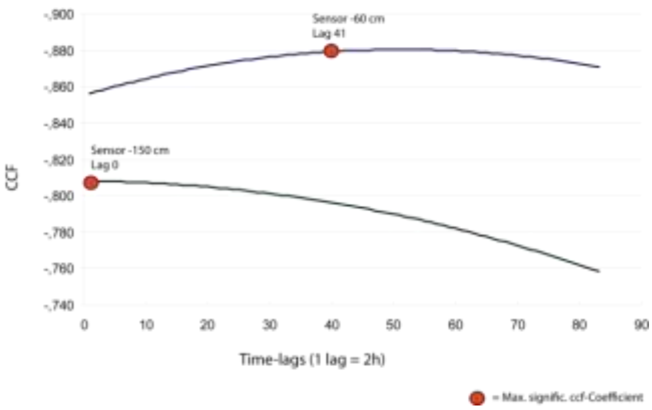

Figure 12: Cross correlation function of two sensors of logger 13 and the groundwater level for September 2013 to January 2014.

For the sensor at 150 cm depth, the time lag is 0. Thus, the soil water content shows a reaction to a rising groundwater within the measurement period of two hours. So, it can be stated that there is a high connectivity between groundwater and soil moisture due to 1) relative small distance between groundwater table and soil moisture sensor and 2) high water-conductivity of the soil. The time until the rising groundwater is notable in shallower soil layers is much longer. The sensor at 60 cm depth has a time lag of 41, which means 3.5 days after the groundwater started rising, the soil moisture content in this layer increased.

Qualitative results show that the surface-groundwater-distance is not the only factor for vegetation condition within the examined corridor. Soil conditions, especially fine-sediment layers, play a crucial role. The soil moisture data indicate that water availability within the measurement period is sufficient to maintain the existing vegetation, disregarding other factors. But one decisive component within the Tugai ecosystem, the morphodynamic, is missing. A comparison of remote sensing data from 1964 and 2014 has shown that the river channel has not changed within that period. River dynamics is important for an establishment of juvenile trees and thus the formation of new forest stands, which is a major factor influencing the vitality -in a sense of rejuvenation- of the forest stands, cf. Thevs et al (2008b).

In the same area in the lower reaches, the analysis of the very high resolution QuickBird and WorldView satellite imageries showed a loss of 180 *Populus euphratica* trees which had been recognized in 2005, a number of 25 new trees were identified until 2011. This affirms that the missing river dynamics, as found along the lower reaches, results in the absence of young trees in the lower reaches. However, a positive tree crown growth with an average crown diameter increase of 1,14m between 2005 and 2011 has been observed (Gärtner et al. 2014).

The ET_a of the natural vegetation is shown in Table 5. In all vegetation types, except for sparse woodland, the ET_a of the growing seasons increases from 2009 over 2010 to 2011. This trend is most pronounced in the dense forests with an ET_a of 735 mm, 777 mm, and 1068 mm during the growing season 2009, 2010, and 2011, respectively. The ET_a calculated from the climate data (Table 5) follows this trend, too. The sum of the daily ET_a values over the vegetation season 2009 measured at the climate station Iminqak nearly equals the ET_a detected from the MODIS satellite images (Table 6). In 2011, the MODIS ET_a is 10.8% higher than the ET_a measured at the climate station.

The trend of the ET_a can be explained as follows: 2009 was an extremely dry year with no summer flood. 2010 was dry, too, until the summer flood started. The summer flood of 2010 was extremely high so that large areas of the natural vegetation, especially dense forests, were flooded and partly stayed flooded until early summer 2011. Therefore, in the second half of 2010 more water was available to be consumed by the natural vegetation. In 2011, there was abundant water available throughout the whole growing season. In addition, during spring and early summer water from flooded areas evaporated.

Table 5: ET_a [mm] of the natural vegetation along the Aksu and Tarim River during the vegetation seasons 2009, 2010, and 2011. N – number of MODIS pixels, Std. Dev. – standard deviation. Natural vegetation: Dense forest – total coverage > 50%, forest – total coverage > 25% and <= 25% with tree coverage higher than shrub coverage, shrub – total coverage > 25% and <= 25% with tree coverage lower than shrub coverage, sparse woodland – total coverage > 10% and <= 25%. *A. pictum* stands cover more than 50% of the MODIS pixels (Thevs et al., 2013).

Vegetation	N	ET_a mean [mm]	Std. dev.	N	ET_a mean [mm]	Std. dev.	N	ET_a mean [mm]	Std. dev.
Wetlands	10	1687	373	10	1660	298	10	1790	248
Dense forest	41	735	135	41	777	149	66	1068	210

Forest	90	554	221	90	612	247	129	725	296
Shrub	24	292	221	24	295	218	38	346	190
Sparse woodland	33	230	225	33	277	238	59	224	272
A. pictum	2	31	65	2	86	22	5	142	80

Table 6: Sum of ET_a during the growing seasons (2009 to 2011) measured with the climate station Iminqak and detected through remote sensing (Thevs et al., 2014).

Year	Sum of ET_a during growing season [mm]		
	Climate station	Remote sensing	Deviation [%]
2009	612	611	0.2
2010		794	
2011	836	929	10.8

During the late 1970s and early 1980s, the local government of Aksu has realized the importance and urgency of urban greening for sustainable urban development, and since then has taken great efforts to increase the forest coverage. As a result, urban green coverage within the built-up area climbed up to 1350 ha in 2012, now occupying more than one third of the urban built-up area. Meanwhile, urban green coverage as percentage of built-up area (Green Coverage Ratio, GCR) also keeps increasing. In 1985, GCR was less than 15%, and in 2012, it reached about 36%. This indicates the continuous attentions and efforts of the relevant urban authorities on urban greening.

By end of 2015, the total amount of water consumption due to urban greening is estimated to reach about 21.3 million m^3 per year (Municipal Government of Aksu, 2007). For the irrigation of urban green space, water saving irrigation methods like sprinkler irrigation and drip irrigation will be predominantly used, and irrigation quota will be controlled to remain below 6750 m^3 ha^{-1} a^{-1} (Municipal Government of Aksu, 2007).

4.5 Economic valuation of environmental change – willingness to pay

The research done in the SuMaRiO subprojects as described in the previous sections illustrated the impact of increasing water shortage along the Tarim River on the vegetation and the living conditions in the lower reaches of the Tarim. The deterioration of trees affects also the ecosystem services that are provided by *Populus euphratica* trees like soil stabilization, breaking the power of sandstorms, filtering dust from the air during sandstorms etc. If this development continues, future generations will find rather harsh living conditions in those regions.

If the Chinese government decides to intervene in the agricultural sector in the middle reaches of the Tarim, in order to make land and water use there more sustainable, it will have to incur considerable costs to set the right incentives for such a development. Government funds will be needed e.g. for paying subsidies or premiums to farmers for the implementation of more efficient irrigation systems and for payments to farmers to compensate them for forgone profits as a consequence of reduced use of fertilizers and pesticides etc. In order to realize a net social benefit with its policy actions, governments have to make sure that the social costs of such a project do not exceed the social benefits. While the project costs can be calculated rather straightforwardly on the basis of market prices (labor cost, capital cost, cost of materials etc.) this is not possible for the social benefits accruing from such a project since there exist no market prices for the terrestrial and aquatic ecosystems of the Tarim River and the ecosystem services they provide.

The welfare economic valuation method tests, improves and applies a specific valuation technique, the so-called Contingent Valuation Method (CVM) as described in section 2.6, for the assessment of the social benefits that would accrue from a practical implementation of the policy measures suggested by the research of other SuMaRiO subprojects, where especially the agricultural project described in section 4.3. is of some importance. In order to determine the benefits of the restoration and maintenance of the natural vegetation along the Tarim River CVM surveys were conducted in summer 2013.

The overall social benefits from a large-scale environmental project in an ecological sensitive region will accrue not only to the people on site but also in other parts of the whole country. That is at least what is to be expected. While the people living on site will benefit from an improved water management directly, there are also benefits from such a project which have nothing to do with the direct utilization of the Tarim water and the ensuing ecosystem services. Also people living in Beijing care for what is going on in the Tarim River Basin and what the living conditions of the local people are. From the perspective of Beijing citizens "desertification" was the most serious environmental problem occurring in the Tarim River BasinTarim River Basin (cf. Figure 14). A possible explanation for this result might be that many parts of China are endangered by desertification. Sandstorms can even be experienced in the city of Beijing (from the Gobi Desert). Therefore also people living in Beijing were willing to contribute financially to an improvement of the water availability situation in the Tarim River Basin.

While environmental improvements in the Tarim Basin would mainly have a direct use value for the local people, it would have a so-called nonuse value for the people living far away from the Tarim (like an existence value or a bequest value, when thinking of future generations). Hence, also the ‘long-distance benefits’ would have to be assessed in order to assess the total value of such a project. Neglecting these benefits would lead to a dramatic underestimation of the overall social value accruing from a potential Tarim water management project since many more people live outside the Tarim River Basin than within that area. A comprehensive assessment of the project in question would, therefore, require that CVM surveys are conducted all over China which is, of course, unrealistic. Therefore, the study was confined to the Tarim region on the one hand and to the city of Beijing as an example of a region far away from the project site on the other. For an assessment of the overall benefits one would have to think about extrapolating the results from Beijing at least to other big cities in China. This would require the application of so-called benefit transfer techniques which, of course, show a number of weaknesses regarding their validity and reliability as is well-known (cf. e.g. Johnston and Moeltner (2014), Kaul et al. (2013), Londoño and Johnston (2012) or Walsh et al. (1992)). To assess the preferences of local people, standardized interviews were conducted in different cities of Xinjiang.

The CVM questionnaire was developed by the Chinese-German research team and continuously adapted based on the results of several waves of pretests and the outcome of multiple citizen expert group meetings in Xinjiang and Beijing. 2 438 persons were interviewed personally by intercept survey in public locations (parks, squares, cafés, etc.) in urban Beijing. To ensure the representativeness of the data a quota sampling approach was used. Due to concerns regarding the safety of interviewers and respondents no intercept survey could be realized in Xinjiang. In order to get a sensible assessment of local people's preferences several workshops were organized in Urumqi, Korla and Lop Nor in July 2013. Workshop participants were recruited via a snowball sampling approach, i.e. the local project partners invited their friends and asked them to tell their friends, relatives or colleagues to join the workshops. Evidently, no representative sample could be obtained like this, but the snowball sampling approach appeared to be the only feasible strategy for assessing the preferences of people living in Xinjiang. At the beginning of each workshop the CVM questionnaire was read out in Chinese or Uighur and completed by the participants. Through this strategy the opinion of 61 local people with diverse demographic backgrounds could be assessed. Some selected characteristics of the survey respondents in the two study sites are displayed in table 7.

Table 7: Demographic characteristics of the survey samples

Variable	Xinjiang[1] N=61	Beijing[2] N=2438
	Mean (std. deviation)	
Sex (Male=1; Female=0)	0.557 (0.500)	0.504 (0.500)
Age	39.7 (8.9)	40.2 (15.4)
Ethnicity (Han=1; Other=0)	0.350 (0.481)	0.919 (0.273)
Native from Xinjiang / Beijing (Yes=1; No=0)	0.754 (0.434)	0.366 (0.482)
Education (University degree=1; High school degree or lower=0)	0.738 (0.044)	0.382 (0.486)
Monthly disposable income (in 1000 RMB)	4.721 (3.700)	8.485 (8.485)

[1] As compared to official estimates (cf. e.g. Xinjiang Statistical Yearbook 2011) elderly people and Han Chinese are underrepresented, while people with university degrees and higher incomes are overrepresented in the sample.

[2] The collected data closely resembles the official data in terms of people's sex, age, ethnic and local background and education. Mean disposable income is significantly higher than the official estimate of 7 732 RMB (cf. e.g. Beijing Statistical Yearbook 2012).

All respondents were asked to express their willingness to pay (WTP) for the implementation of the preservation project. In accordance with economic welfare theory, individual WTP statements can be interpreted as the utility (in monetary terms) a respondent receives from the project in question. If the survey sample was representative of the population affected by such a project, the WTP statements from the sample could be extrapolated to all individuals affected. The mean WTP of the respondents from Xinjiang amounts to 48 RMB per month, corresponding to approximately 1% of an average respondent's monthly disposable household income (4731 RMB). Respondents from Beijing had a mean WTP of 107 RMB, which is also about 1% of a respondent's monthly disposable household income (8487 RMB). According to these results, the appreciation of the preservation project in the Tarim River Basin is approximately the same in both study sites. Of course, the gathered data is not representative for the Chinese population as a whole; therefore, these WTP estimates cannot be extrapolated to all individuals affected. Apart from the WTP for the preservation project, people's opinion on different aspects of environmental preservation in the Tarim River Basin was assessed. Respondents were asked to rank several ecosystem services (ESS) provided by the natural vegetation in the Tarim River Basin according to their importance for society. In addition to that they also had to judge the seriousness of several environmental problems in the Tarim River Basin. The results are displayed in Figure 13 and Figure 14. The preferences for the different ESS turned out to be quite similar in both study sites. Respondents from Xinjiang and from Beijing considered the mitigation of dust and sandstorms as the most important ESS, the provision of useful herbs was perceived as least important. Also the ranking of environmental problems in the Tarim River Basin was the same in both study sites. Desertification of the landscape was considered most serious, followed by sandstorms and dust and the extinction of plants and animals was ranked least important.

The survey results show that also people living far away from the project site appreciate the benefits from environmental preservation in the Tarim River Basin as much as local people do. Therefore, confining valuation surveys to the local population only might lead to a systematic undervaluation of environmental improvements and thus to a potential rejection of a socially beneficial project by political decision makers.

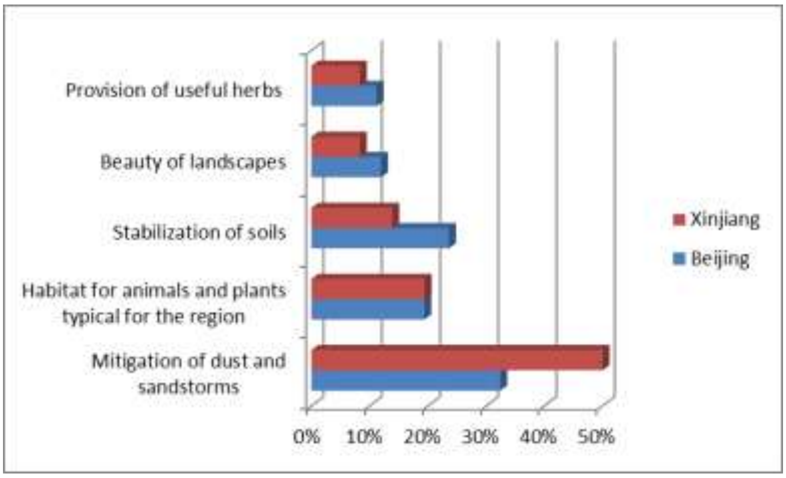

Figure 13: Common people’s opinion on the restoration and maintenance of the natural environment - Importance of ecosystem services provided by the riparian vegetation in the Tarim River Basin

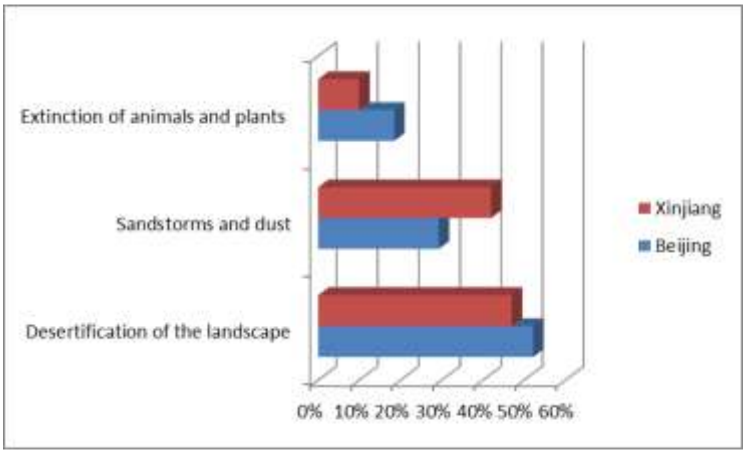

Figure 14: Common people’s opinion on the restoration and maintenance of the natural environment - Seriousness of environmental problems occurring in the Tarim River Basin.

4.6 Transdisciplinary research

Transdisciplinary research is an iterative and recursive process, which requires continuous reflection and adaption, as new knowledge emerges and is brought into such a consortium like SuMaRiO. The approach to transdisciplinary research here has in overall improved knowledge integration among multiple disciplines and enabled, although partially, knowledge integration from inside and outside of academia. The integration of existing knowledge, which takes stakeholder perspectives and needs into account, is essential for the development of a usable decision support tool (DST) as well as identification of actually implementable land and water management strategies that aim at maximizing ecosystem services in the Tarim River Basin.

4.7 Decision support tool

The key-resource in the Tarim River Basin is water, for which anthropogenic activities and natural ecosystems compete. Water is delivered from the headwaters of the Aksu River with currently increasing runoff. The competition for water though has not eased, mainly because new land for agriculture, which completely depends on irrigation, has been reclaimed at a high speed. Furthermore, it is unsure, how the runoff from the Aksu headwaters will further develop in the course of climate change so that no weakening of the water competition can be expected from the supply side. Therefore, a sound allocation of water must be established, in order to balance the water competition on the demand side.

This interdisciplinary project will therefore deliver a decision support tool (DST), build on the participation of regional stakeholders and models based on results and field experiments from the data collection phase. This DST finally shall assist stakeholders in balancing the water competition acknowledging the major external effects of any water allocation. Though, the complexity of the project cannot fully be implemented in a DST, as the DST has to be understood and used by all kinds of stakeholders with different kinds of backgrounds. The simplicity of the DST will help them to understand the whole ecological system of the Tarim River Basin. The DST is based on simple rules, which can be filled with new actual data by every stakeholder according to his/her special background, but the other data they do not have can still be used and will give a more accurate picture of the system. Through this DST the SuMaRiO project brings a new kind of decision support to the region and will help to foster sustainable development of the region.

On the way to develop the decision support tool, the multi-level stakeholder dialogues (MLSDs) were an important tool to implement project results. With its help important indicators for the definition of climate and socio-economic scenarios and management alternatives have been carved out. Also representative indicators for all relevant ecosystem services have been identified and weighted for the presentation of land and water management consequences. These results form the basis of the DST.

The workflow of the DST is as follows:

In the first step three different planning years for the climate and socio-economic scenarios and management alternatives can be chosen arbitrarily. For each of these years the DST-user can define up to three different climate and socio-economic scenarios by choosing assumed values for explaining indicators like increase in world market cotton price or increase in average daily temperature. Optionally the user can decide on probabilities for the realization of the scenarios defined before.

In the second step up to ten management alternatives can be planned for the upper, middle and lower reaches of the Tarim River Basin for the three different years. Alternatives differ, e.g., in the amount of water that is assigned to the different regions or the percentage of land that can be used for agriculture.

In the next step the weights of the ecosystems agriculture, which includes the economic benefits, (virtual) value of riparian forests, grassland and urban vegetation can be weighted, just as the corresponding ecosystem services and the representative indicators. The DST recommends choosing the settings from the stakeholder dialogues but can be overruled by the user. Furthermore the side-constrained multi-criteria goals of land and water managers can be defined. E.g., the one goal could be to maximize the water quality and at the same time to maximize the benefit originating from cotton production. As a side constraint a minimal virtual value of riparian forests has to be guaranteed.

The first three steps constitute the input phase and are followed by the computation and the analysis phase. In the fourth step the short- and long-term consequences of each management alternative are calculated in a quantitative way as well as in a semi-quantitative way for each part of the Tarim River Basin. Here “consequences” mean the development/change of the different indicators. This development/change is computed on the basis of the knowledge and models developed within the SuMaRiO project. For some computations Fuzzy-Logic is employed. With the help of the defined goals for each representative ecosystem indicator, one standardized utility value respectively standardized goal achievement value can be calculated. Based on the standardized utility value a comparison of each indicator with the result of the current year is enabled. It is shown if the alternative generates an improvement or a decline in the standardized utility value of the indicator. With the aggregation of the utility values to one significant value, in terms of utility analysis, all planned management alternatives can be compared among one another and is the first part of the output. In addition the DST performs sensitivity analyses by modifying crucial parameters of the chosen management alternatives before. This yields to more insight in the allocation problem and forms the last step of the DST process.

5. Major findings and Conclusions

The combination of scientific findings of an interdisciplinary project like SuMaRiO is quite challenging. The scientists from various disciplines have different foci in the geographic region, even the language and definitions of common used termini have to be cleared in the different fields of research and find an interdisciplinary definition. In the SuMaRiO project another difficulty are the three different cultural backgrounds of the scientists involved - German, Chinese, and Uighur. The point of views on a specific research topic, scientific methods and the way of communication are different. To find a context between the interdisciplinary and intercultural project members communication was the only way to avoid and clarify misunderstandings. The main communication platform of SuMaRiO is the project’s official and internal web page. The description of the project, the goals of every workblock and the detailed work plan can be found there in the project’s main languages, German, English and Chinese. Exchange of data and the access to reports and the project’s publications is achieved via the internal web page.

Nevertheless, the main and most efficient way to exchange ideas, solve misunderstandings between disciplines and cultures is the personal communication in workshops, conferences in

Germany and China but also via telephone or Skype. Another important way to improve the intercultural cooperation is staying in the respective foreign country giving a better understanding of how work is done is the other culture. Trust and motivation for the interdisciplinary and intercultural cooperation was strengthened by collective informal gatherings.

For future cooperation between German and Chinese institutions as well as to foster the relationship between the scientists involved, the common platform 'Sino-German Joint Research Center for the Management of Ecosystems and Environmental Changes in Arid Lands (MEECAL)' was established. It provides the basis for the exchange on issues to arid lands and its ecosystems – with a special relation to Xinjiang.

The results of the SuMaRiO project will be archived by the MEECAL platform (http://sinogermanmeecal.de) and will help with the further use of the data. For the implementation of the project results, Chinese stakeholders were involved from the beginning of the project to support specific issues on land use and water management in the region. In the upcoming implementation phase of the project, workshops will be held to train the local upcoming stakeholders on the decision support tool and to convey the findings of the project as well as a better understanding of the different cultures involved.

Due to climate change, melting of glaciers and snow in the surrounding mountains will increase. Thus, the river runoff of the Tarim River will increase in the nearer future. This increase in water availability may motivate agricultural producers along the Aksu River and upper reaches of the Tarim to further increase their production area. This may then result in an even stronger aggravation of water shortage and salinity related problems under the projected decrease in river runoff in the distant future.

With the predicted expansion of the agricultural area in the upper reaches more cotton will be produced. But the cultivation of cotton on soils with high degree of salinity, which is likely to occur as arable land is encircled by desert and already degraded soils, reduces the water use efficiency, since much irrigation water is needed for leaching salts out of the root zone. This increases the water consumption in upper reaches of Tarim and leads to water shortage in middle and lower reaches.

This conflict between the upper and the lower reaches of the Tarim River already exists. The Chinese government reacted on this conflict with the Ecological Water Diversion, within which water from upstream is channeled through the midstream river section to the downstream riversection. Additionally, water from the Bosten Lake and the Kenqi River is transferred into the lower reaches of the Tarim (Peng et al., 2014). The aim of these water diversions are the preservation of the riparian forests, especially *Populus euphratica* trees playing an important role in fighting desertification in the region.

The results of the evaluation of the satellite images on the recovery of *Populus euphratica* trees confirm the assumption that the long term ecological restoration of degraded riparian Tugai forests along the lower reaches of the Tarim River has beneficial influence on the *P. euphratica* growth. The detected expansion of above ground green biomass corresponds to natural succession and suggests improved groundwater conditions after Ecological Water Diversion from 2000 until 2011 (Zhandong et al., 2009).

The reason of the expansion of the *Populus euphratica* trees lies in their natural regeneration. Under the given climatic conditions of *P. euphratica* stands from seedlings is only possible along rivers in river beds or after flooding events, when the upper soil has been thoroughly wetted and the distance to the groundwater is small enough to be bridged by rapid vertical root growth (Runge, 2004; Thomas, 2014). Thereafter, the distance to the groundwater may become larger by lowering of the water table (due to groundwater use by the human population or by natural shifts in the course of a river) or by sand accumulation. In some phreatophytic species (species who rely on access to groundwater), including *P. euphratica*, root and shoot growth can keep pace with an increase in the distance to the groundwater and, thus, the trees are capable of maintaining contact to the water level, provided that the decrease in the groundwater level is not too rapid and the distance to the groundwater does not become too large. Due to a continuous increase of the groundwater distance, the canopies of *P. euphratica* eventually are positioned at a distance of much more than 10 m above the water table without losing contact to the groundwater (Gries et al., 2003). This process explains the occurrence of phreatophytic vegetation at sites with a large distance to the water table. At such sites, however, natural generative rejuvenation of the stands is not possible any more, and vegetative regeneration by root suckers (e.g., Wiehle et al., 2009) as well as shoot growth can be hampered due to a decrease in hydraulic conductance from the soil to the leaves (Gries et al., 2003). Thus, the density of *P. euphratica* stands will decrease with increasing distance to the water table and increasing age, and, eventually, the stands will die off (Runge, 2004).

Our results indicate that in the Tugai forests, the stem diameter increment of *Populus euphratica* decreases with an increase in tree age and in the distance to the groundwater. As tree age and groundwater distance are interrelated in the life history of the stands, it is difficult to separate the effects of these two factors from each other. According to previous studies, however, basal area increment of *P. euphratica* also decreases along a gradient of groundwater distances from 7 to 23 m in trees that exhibit similar basal areas; in those trees, larger distances of the tree crown to the water table had been brought about by shifting sand dunes and subsequent stem elongation (Gries et al., 2003). The decrease in basal area increment of those trees could be attributed to a decrease in the leaf-specific hydraulic conductance on the flow path from the soil to the leaves, which was also related to the leaf water potential and the stomatal conductance of the leaves (Gries et al., 2003). Thus, it can be assumed that along our study plots near Yingbazar, groundwater distance rather than tree age is the principal reason for the differences in stem diameter increment. Impairment of shoot growth due to wood harvest by the local population, which plays an important role at several locations along the Tarim River, can be excluded as a major influencing factor on shoot growth because our study plots either belong to protected nature reserves (plot GD1) or are located at relatively large distances from the small villages in that region (plots GD2 and GD3).

The fact that only the poplars on the plot with the small groundwater distance, but not the trees growing at larger distances to the water table exhibited a significant correlation between the standardized stem diameter increment and the preceding year's river runoff might be somewhat surprising at first glance. However, similar results have also been obtained from studies on other phreatophytic species. Sapling mortality of the riparian tree species *Populus fremontii* and *Salix gooddingii* was higher at a site with a smaller distance to the groundwater, but with a more severe interannual decline of the water table than at a site with a larger distance to the water table, but less change between years (Shafroth et al., 2000). In that study, the differences in sapling mortality were attributed to the conditions under which the roots were formed.

In conclusion, our results provide further evidence that a larger distance to the groundwater results in reduced stem growth; thus, they are in accordance with findings of several other studies on woody phreatophytes (cf. Thomas, 2014). The sensitive growth response of the trees on plot GD1 to changes in the water supply via the Tarim River should be taken into consideration in future planning of water distribution on a landscape scale: the negative effects of diverting water from sites with a small distances to the water table to sites with larger distances to the groundwater might outweigh any positive effect on *P. euphratica* stands that grow already at larger distances to the water table and exhibit a low productivity anyway. However, a further decline of the water table should also be avoided in those stands on order to prevent a further decline of the riparian forests, which is already widespread especially at the lower reaches of the Tarim River (e.g., Feng et al., 2005).

In combination with the results obtained by the hydrological working groups and on the basis of modeling approaches for the future runoff of the Tarim River under the projected climatic change, the future growth increment of the *P. euphratica* stands growing at close distances to the ground water can be estimated, and predictions on the productivity of the stands under different scenarios of future river runoff can be developed.

The simulation of future water availability and the developing of runoff scenarios for the region support decision makers in managing water and land in the region. Additionally the assessment of the overall social value of a project which would contribute to a restoration and protection of the ecosystem services along the Tarim River of all people directly or indirectly (also emotionally) affected in terms of their willingness to pay for that project is helpful for politicians for two reasons. On the one hand they can compare social costs and benefits in terms of the same measuring units, i.e. money, in order to decide if the realization of such a project is socially profitable and, therefore, advisable or not. In this use the CVM is a political decision tool. On the other hand the aggregate willingness to pay (WTP) of the winners of such a project can be included in a system of Payments for Ecosystem Services (PES), where those who receive the benefits from ecosystem services make compensation payments according to their preferences to those who provide these benefits (cf. e.g. Ahlheim and Neef (2006)). In this use the CVM is also an instrument for the practical implementation of environmental projects since it helps financing such projects in an efficient and also equitable way: the overall sum of all WTP is an indicator of the extent to which the benefiters of an environmental project wish to have an improvement of the provision of the ecosystem services in question (efficiency aspect), and if the individual benefiters would be forced to pay according to their individual WTP, which reflects the utility gain they expect from that project in monetary terms, such payments would also be equitable in the sense of the equivalence principle of public finance theory.

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