

# Complexities in modelling water availability in the water-scarce Aksu catchment, northwest China

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**Abstract:** The Aksu River, located in an arid region of northwestern China, is a snow and glacier melt-dominated river originating in the Tian Shan mountain range. Over the past 40 years, an increase in river discharge was reported, assumed to be caused by enhanced glacier melt due to a warming climate. Rapid population growth and economic development have led to a significant expansion of irrigation agriculture in the oases along the river, resulting in a decline of river discharge downstream and water shortage for floodplain vegetation. Hence, pressures on water availability for agricultural land has become ever more important in this water-scarce region under a warming climate. Complexities of this unique hydrological system are presented. Additionally, a combined modelling strategy using the ecohydrological model SWIM and the water resource management model WEAP is proposed. The upstream natural river discharge could be simulated by the semi-distributed model SWIM, while the downstream water management in various irrigation areas could be analysed by WEAP. Application of these models for this glacier-fed, arid basin is challenged by data scarcity and significant hydrological engineering modifications during the last decades. Insufficient data on water use adds further uncertainty.

**Keywords:** Aksu; model coupling; SWIM; WEAP

## 1 INTRODUCTION

In large parts of China, climate change as well as rapid land use change induced by the expansion of agricultural land have put increasing pressure on water resources [Piao et al., 2010]. This development is of specific importance to the semi-arid and arid areas of north and north-western China where irrigation water is inherently scarce [Thomas, 2008]. Information on the hydrological conditions under these changing factors is of crucial importance to land use planning and water management. Climate change studies indicate an increase in annual mean temperatures as well as changes in precipitation patterns throughout China in the last five decades [Ding et al., 2007] with mostly negative implications for water availability. This trend is generally set to continue as global climate change scenarios project [Meehl et al., 2007], although associated with high uncertainties. Climate change impacts, however, show great heterogeneity throughout China, making regional impact assessments indispensable.

Most of the Aksu River basin is located in China's northeastern province, Xinjiang, which has experienced a mean temperature rise of 0.04 °C per year and an increase of winter precipitation of 1.5% per year in the past 50 years [Ding et al., 2007]. This has led to enhanced glacier and snow melt in the Tien Shan mountain range [Ding et al., 2006;

Aizen et al., 1995], the source of the glacier and snow melt dominated Aksu River. The observed increase in river discharge in the lower parts of the catchment has enabled the expansion of irrigation agriculture and population growth [Wang et al., 2008, 2009].

Some research has addressed the hydrological complexities present in the Aksu basin to advice water management practices. Wang et al. [2008] and Liu et al. [2006] investigated the trends in river discharge over the past half century indicating an increase. Tang et al. [2007] and Wang et al. [2009] report on the intensive agricultural use of water resources and its impact on river discharge. They found that the rapid increase in abstractions for irrigation as well as large-scale diversions have severely altered the river discharge. Simulating the complex and dynamic hydrological changes in the Aksu basin is mainly challenged by data scarcity. Both river gauge and meteorological stations are sparsely distributed in this hyperarid, mountainous terrain. Ouyang et al. [2007] tested several forecasting approaches for both water availability and flood occurrence under those data-scarce conditions including several statistical approaches and one lumped model. In a similar study, Ouyang et al. [2008] compared a snow melt and a rainfall runoff model in a headwater part of the basin. While statistical models generally performed better as less data is needed, the physical basis for long-term modelling is lost. Also, previous work has so far failed to integrate agricultural abstractions. A novel modelling technique is needed to incorporate the limited observation data as well as publicly available global data into process-based model. That is, a spatially distributed approach is needed that is able to incorporating water abstractions for irrigation.

The objectives of this study are to describe the complexities of the Aksu catchment and propose a coupled modelling strategy.

## 2 THE AKSU CATCHMENT

The Aksu catchment reaches from the glaciated Tien Shan mountain range in the north and west to the hyperarid Taklamakan desert in the southeast where it becomes the main tributary of the Tarim River (see figure 1). The catchment can be divided into two distinct parts: a) The two headwater subcatchments upstream of Xiehela and Shaliguilanke are mountainous catchments which mostly lie above 2000 m above sea level and b) the part downstream of these stations to the confluence of the Tarim river.

The latter part is dominated by extensive irrigation agriculture and thus significant modifications to the river routing especially downstream of Xidaquiao station. Therefore, the catchment shape is in effect spreading out from Xidaquiao station. Due to the construction of irrigation canals and reservoirs over the past five decades reliable long-term observations are sparsely available for this lower part. It is considered highly dynamic

Table 1: Stations considered. Catchment area and station altitude based on the SRTM DEM. Mean discharge is based data from 1957-2010, except for S4, which is based on limited data from 1971-76.

ID	Station	River	Area <i>km<sup>2</sup></i>	Altitude <i>m asl.</i>	Mean Q <i>m<sup>3</sup> · 10<sup>8</sup></i>	Location <i>°E °N</i>	
S1	Xiehela	Kummalike	12816	1487	48.67	79.617	41.567
S2	Shaliguilanke	Toxkan	19166	2000	27.67	78.600	40.950
S3	Xidaquiao	Aksu	43123	1100	64.54	80.250	41.117
S4	Yimapaxia	Aksu		1037	29.27	80.604	40.649

with the catchment boundary changing over time. Table 1 shows the basic statistics of the three considered stations.

The headwater originates in altitude ranges of 2000 to 7000 m with about 19% glacier cover in the Xiehela and 2% in the Shaliguilanke subcatchment. The Kummalike and Toxkan River merge to form the Aksu River in the middle part where large alluvial plains span into the funnel-like terrain towards Aksu City. Glacier distribution and irrigation units are shown in figure 1. Vegetation and agricultural land is mainly distributed along the rivers with channel diversions to reclaimed large parts of the alluvial plain. The so-called linear oases have experienced an expansion from 1010 to 2840 km<sup>2</sup> from 1949 to 1990 with an increase in population from 274 to 845 thousand people [Hong et al., 2003].

The climate is characterised by mean winter conditions with temperatures between -15 to -8°C and precipitation of less than 10 mm per month. Summers are wetter with precipitation rates of 40 to 50 mm per month in the upper catchment, temperatures rise to 10 to 20°C in the lower parts. Most river runoff is thus observed in spring and summer in the snow and glacier melt period. Evapotranspiration typically exceeds precipitation with an estimated annual rate of 1800 mm in the cultivated lower part [Tang et al., 2007].

The river regime at the four stations shown in figure 1 clearly indicate a decline of discharge from the headwater part to the lower parts as figure 2 shows. In the snow and glacier melt period from April to September, the combined headwater discharge exceeds discharge at Xidaquiao station by 10 to 30%. Limited observed discharge at the intermediate station Yimapaxia indicates a further decline in discharge from Xidaquiao station by 40%. This is assumed to be caused by diversion for irrigation and thus enhanced evapotranspiration. Simultaneously, warmer temperatures observed throughout the catchment

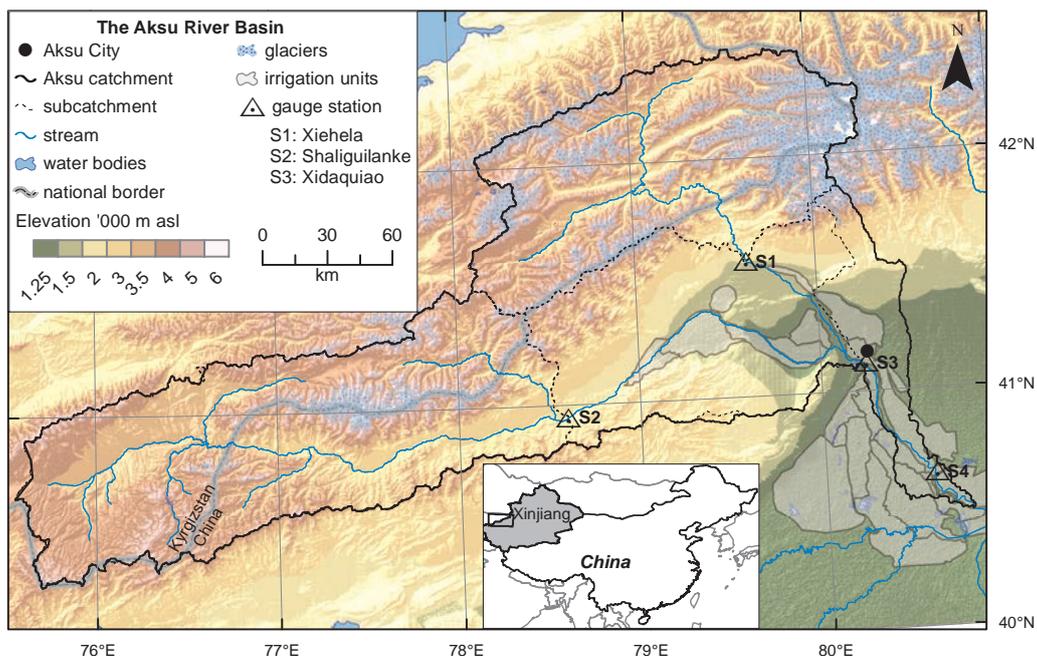


Figure 1: The Aksu catchment based on the SRTM DEM. As water is channelled to both sides of the Aksu river downstream of Xidaquiao, the catchment is effectively larger and widens out as the irrigation units suggest.

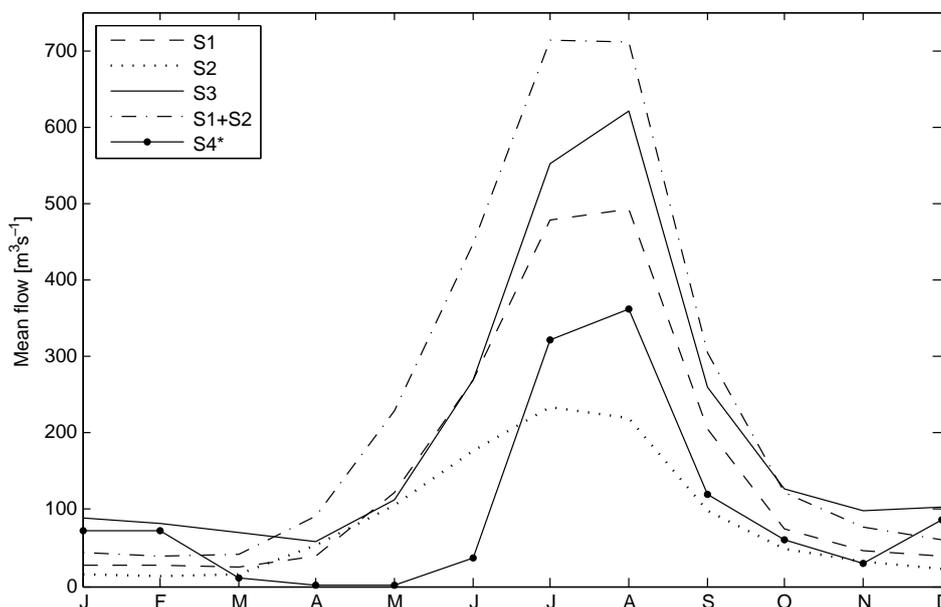


Figure 2: River regime of the 4 stations shown in figure 1 in order of flow and the combined flow of the headwater stations. Discharge decreases progressively downstream.

over the last five decades have enhanced snow and glacier melt in the headwaters [Wang et al., 2008; Liu et al., 2006]. This is evident in annual river discharge in figure 3. All three stations show an increase, especially in the last three decades with a mean annual increase of 0.5% at Xiehela, 1.4% at Shaliguilanke and 0.2% at Xidaquiao. The difference in increase rates between headwater and middle catchment is further evidence for increased water abstractions between the stations.

### 3 A COUPLED MODELLING APPROACH

Considering the hydrological complexities described above, analysis of future change of water resources is vital for an integrated water resource management. A modelling system has to answer questions such as *a)* how will climate change impact the water resources in the catchment? *b)* if glaciers are receding, when will the discharge start to decline? *c)* how does the snow cover distribution change in given climate scenarios? *d)* what impacts would improvements in irrigation efficiencies have on water availability? *e)* what are likely the land use change scenarios and what impact would they have on water availability downstream? *f)* what are the uncertainty ranges of modelling results?

To address these questions, an integrative modelling approach is proposed here. The process-based model SWIM is to be coupled with the conceptual model WEAP to combine both their advantages. Figure 4 shows the data flows diagrammatically between the different input data and the linking between the two models.

The Soil and Water Integrated Model (SWIM) was first applied for the European catchment of the Elbe River in northeastern Germany [Krysanova et al., 1998, 2005; Hattermann et al., 2005]. It is based on the renowned Soil and Water Assessment Tool (SWAT) [Srinivasan et al., 1998] and MATSALU [Krysanova et al., 1989]. SWIM is a

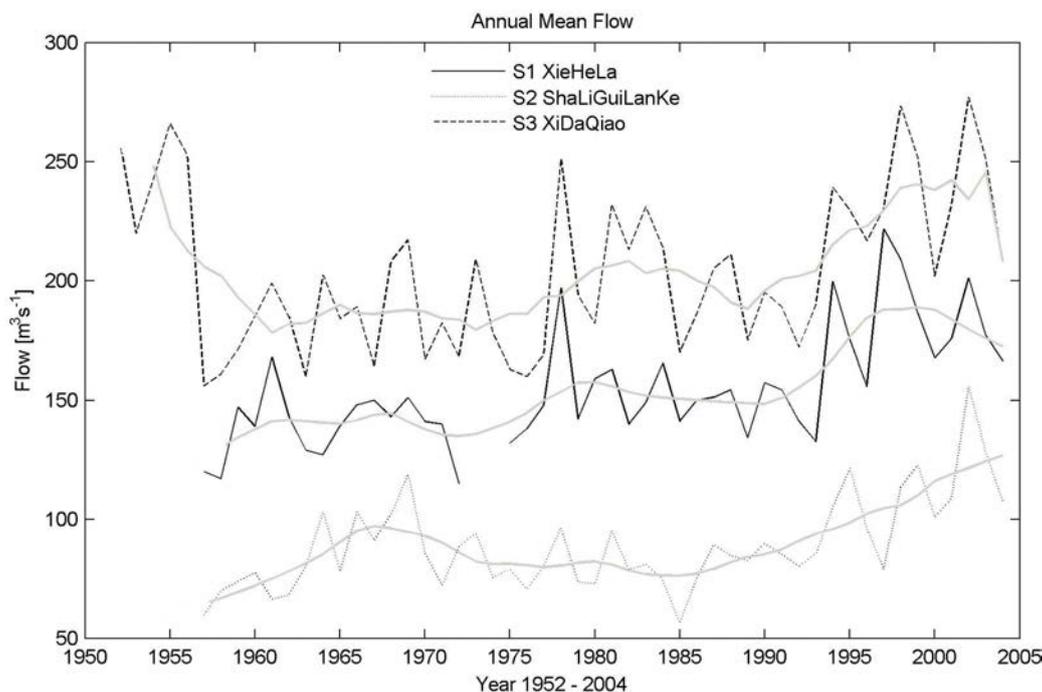


Figure 3: Annual mean flow for the three long-term observation stations. A five-year low-pass filter is shown in grey.

semi-distributed, ecohydrological model for meso-scale catchments, integrating hydrology, nutrient transport and crop growth for integrated catchment management. Its basic spatial structure is the catchment, subcatchment and the hydrotopes (also known as hydrological response units (HRU)). Spatial input data includes a digital elevation model (DEM), land use and soil maps with an associated soil database. Precipitation, temperature (mean, max, min), humidity and solar radiation are needed to drive the model at daily time steps. Most hydrological processes are represented in an semi-empirical fashion including the degree-day method for snow and glacier melt.

The Water Evaluation and Planning (WEAP) is a conceptual model simulating river discharge from observed river discharge, abstractions, return flows and known reservoir volumes. Through its representation of the river network, canals and reservoirs it is designed to device an Integrated Water Resource Management (IWRM) plan [Yates et al., 2005]. WEAP is designed to analyse a range of management issues including anticipated demands, operational objectives and ecosystem needs.

So far the models were applied to each part individually to assess both models suitability. For the headwater part, Nash-Sutcliffe efficiencies (NSE) and deviations in water balance varied slightly between the two stations compared to monthly observations. At Xiehela this is 0.77 and 5% and at Shaliguilanke 0.78 and -3%. For WEAP, monthly NSE values of 0.94 and water balance of -5% were achieved using WEAP. The monthly river regime is reproduced well. Peak flows are simulated with deviations up to  $\pm 10\%$ , low flows however, are underestimated in all years. At this stage only preliminary results are mentioned with a full implementation planned.

The implemented model coupling would provide an integrated environment to assess hydrological and related impacts for various climate, land use change and irrigation scenarios. It is relevant to similar hydrological settings with snow and glacier melt dominated

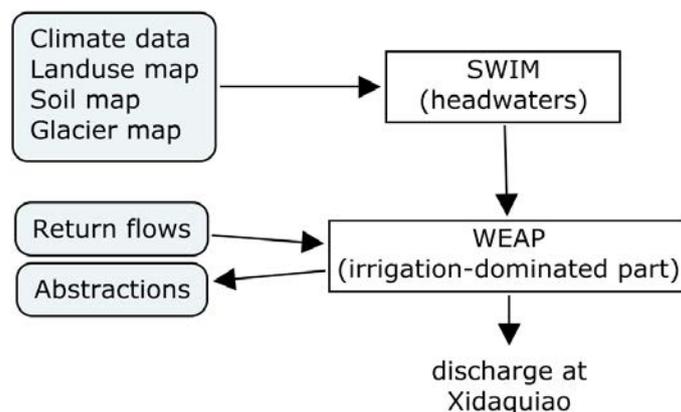


Figure 4: Diagrammatic representation of the model linking to model river discharge at Xidaquiao station.

headwaters and an extensive irrigation agriculture in the lower catchment.

#### 4 CONCLUSIONS

The complexities of the arid Aksu catchment are presented emphasising the heterogeneities of the hydrological system. On the one hand, discharge is increasing in the snow and glacier melt dominated headwaters, on the other hand, water abstractions due to rapid expansion of irrigation agriculture lets discharge decline downstream. Modelling approach must make allowance for the data scarcity in a highly mountainous terrain in the headwaters and in a highly dynamic and modified river routing downstream. A coupled modelling approach is proposed using the process-based, semi-distributed model SWIM for snow and glacier melt dominated headwater catchments and the water resource management model WEAP for the arid lower catchment. The full implementation with a two-way interchange between the models is planned with improvements in SWIM's snow and glacier modules. The final model could device an integrated approach to climate and land use change impact assessments and water resource planning in similar regions. The physical basis of SWIM allows for a range of scenarios to be analysed including climate change, land use change and irrigation scenarios.

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