2. Study areas: The Heihe River Basin and Wuliangsuhai Lake at the Hetao Irrigation District

Niels Thevs
Konrad Ott
Lilin Kerschbaumer
Ping He

2.1 Introduction

Central Asia, which extends from the Caspian Sea to northwest China and Mongolia, is largely covered by deserts, steppes and mountain ranges. Within this huge dryland area, there are numerous wetlands, either distributed along river systems or island-like dispersed in depressions. In terms of area, the former predominate over the latter. Naturally, there is a mosaic of mainly *Phragmites australis* dominated wetlands and riparian forests distributed along the rivers of Central Asia (Ogar 2003). These wetlands and forests play a crucial role for the biodiversity of that region, because they offer habitats for wildlife and most plant species in the drylands of Central Asia (WLI 2012). Ever since, the rivers have attracted people to settle and establish themselves around oases, as this warranted a water supply in the dryland areas of Central Asia. Some of those oases have a history of several thousands of years and are part of the Silk Road, like Buchara and Samarkand, Kashgar, Hotan or Zhangye; however, during the past six decades, the speed of land reclamation and expansion of settlements increased tremendously. Huge areas of the natural ecosystems along the rivers have been converted into either agricultural land or settlements or have been degraded due to water shortage. The most prominent example is the expansion of cotton in the former Soviet Union, which resulted in the desiccation of the Aral Sea and degradation of wetlands along the Amu Darya River (Glantz 2005). A similar example in China is the Heihe River.

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The downstream section fell dry in the 1970s in the Hetao Irrigation District, a riparian wetland complex along the Yellow River has been converted into agricultural land. *P. australis* played and still plays an important role for people in Central Asia. It used to be, and in parts of the region still is, the major fodder plant for livestock (Thevs et al. 2007).

Traditionally, it was used for mats in house construction. Today, it plays a role as raw material for e.g. paper production or insulation material (Köbbing et al. 2014a), and as energy source (Patuzzi et al. 2013a). Furthermore, as population along the rivers of Central Asia increase and settlements expand, wetlands play an increasingly important role with respect to water purification. Against this backdrop of degradation of wetlands in Central Asia, from past to present, their significance throughout the whole region of Central Asia, a wide range of initiatives has been undertaken in order to protect and restore wetlands. Examples are protected areas, which have been established during the past 30 years, e.g. Nizhny Amu Darya Biosphere Reserve, Uzbekistan; Amu Darya State Reserve, Turkmenistan; Ili Delta Nature Reserve, Kazakhstan; Tarim Huyanglin National Nature Reserve, Xinjiang, China; and Ejina Huyanglin Nature Reserve, Inner Mongolia, China. Wetland protection in a dryland region, like Central Asia, is closely connected with the water resource management of the rivers, which sustains particular wetlands.

The vast majority of the rivers in Central Asia face upstream-downstream conflicts over water. Upstream countries, regions or water users divert and consume water at the cost of downstream riparian countries or regions. When the cotton production was promoted in the previous Soviet Union, it occurred at the cost of the Aral Sea as well as the Amu Darya and Syr Darya deltas. In a similar way, at the Tarim River water users upstream consume water with the result that downstream users suffer water shortages. The Heihe River Basin represents such upstream-downstream conflicts over water distribution in river systems. Wuliangsuhai Lake is a showcase for a wetland suffering eutrophication in a context of an irrigation scheme – via the Hetao Irrigation District. Hence, two key points of examination arise: (1)

in the former, water quantity and allocation of certain water amounts and (2) in the latter, just water quality. Therefore, both sites are showcases for the water allocation and water quality problems, which are prevalent throughout Central Asia.

2.2 The Heihe River Basin

The Heihe River Basin covers an area of 120,000 km^2 and is shared by Gansu Province and Inner Mongolia. The headwaters of the Heihe River are located in the Qilian Mountains in Gansu Province south of the city of Zhangye (Figure 1). The Heihe ends in the two terminal lakes West and East Juyanhai Lake close to the border with Mongolia (Li et al. 2012a). From the Qilian Mountains, the Heihe River flows into the oasis of Zhangye, which has a population of about 1.3 million inhabitants. Within the area of Zhangye, about thirty small rivers flow down from the Qilian Mountains, which now are diverted into an irrigation zone. Only during spring or high floods some of these rivers contribute to the Heihe River's runoff. Once the Heihe leaves Zhangye, it flows as a so-called losing stream through mainly gravel deserts northwards from Gansu into Inner Mongolia. This is a common feature of rivers in the whole of Central Asia, in which they originate from mountain areas due to a surplus of precipitation, i.e. rain and snow. The rivers thus are fed by rainfall and melt-water from snow and glaciers alike. Thereby, the runoff of the rivers on the western side of the Tianshan and Pamir mountains is melt-water dominated, e.g. Amu Darya and Syr Darya. In contrast, rainfall contributes to a significant part of the runoff of rivers east of the Tianshan and Pamir, like the Tarim and Heihe. In the Tarim and Heihe river basins, the precipitation maximum is in summer, while the former river basins receive most precipitation in autumn and spring. In higher elevations, where the rivers originate, spring and autumn precipitation falls as snow.

Once rivers like the Heihe flow away from the mountains where they originate, the rivers turn into so-called losing streams. This means that such rivers constantly lose water into adjacent groundwater aquifers or via evaporation (Hou et al. 2007). Parts of rivers throughout Central Asia vanish in the desert due to this water loss, like the Keriya or Niya in the Tarim Basin or the Chu River in Kazakhstan. Other rivers, like the Amu Darya, Syr Darya, Ili, Tarim or Heihe become smaller, further downstream, and drained or still drain into terminal lakes. So all rivers in Central Asia, except the Irtysh, are endorheic rivers, which means that they do not reach the ocean. Thus, the Heihe River represents an endorheic river basin of Central Asia.

The climate in the Heihe River Basin is arid and continental. In the Qilian Mountains along the headwaters of the Heihe River, the annual precipitation is about 400 mm. In Zhangye at the foothills of the Qilian Mountains, it is 170 mm and further north in Ejina it is only 60 mm. About two thirds of the annual precipitation is concentrated in the months from June to August. This precipitation is maximised when it falls together during the snow and glacier-melting period in the Qilian Mountains, which results in annual summer floods in the Heihe River. Such summer floods naturally occur in all rivers of Central Asia.

The natural vegetation along the Heihe River consists of a mosaic of riparian forests and reed beds dominated by *P. australis*. The largest reed beds are located around the two terminal lakes of the Heihe. This area was an important pasture ground for Mongolian herders. The Mongolian people here are a minority within China. Today, reed beds can be found around the eastern terminal lake and smaller patches along the Heihe. In Zhangye, a wetland park has been established, in order to create a recreation site. Furthermore, small reed stands are distributed all over Zhangye, which receive wastewater and play an important role in purifying wastewater.

Due to the arid climate, all agriculture along the Heihe River depends on irrigation. The history of irrigation in Zhangye has been documented for more than 2000 years (Feng & Cheng 1998). During that time, no irrigation agriculture was known along the lower reaches of the Heihe River in present day Inner Mongolia. Starting in the 1950s, the area under agriculture along the Heihe, in Zhangye, was enlarged like in all other oases in northwest China (Gruschke 1991) from 82,600 ha in 1949 to 260,000 ha in 1995 (Feng & Cheng 1998) and 253,300 ha in 2012 (personal communication with the agriculture administration of the city of Zhangye 2012). Cropland also was reclaimed in Ejina County. While before 2000, the major crops along the Heihe were cotton and paddy rice, now the major crop is seed corn. Most of the seeds, which are used to crop corn in China, are produced in Zhangye.

Figure 1 – Map of the Heihe River Basin, China (Liu 1997).

This increase of cropland area resulted in increasing demand for irrigation water, which was diverted from the Heihe River. The terminal lake West Juyanhai has been dried out since 1961 as well as most of the western branch of the Heihe in Ejina. The terminal lake East Juyanhai Lake covered 35.5 km² in 1958, shrunk to 23.6 km² in 1980 and dried up completely in the beginning of the 1990s (Ejina Qizhe 1998). In 2002, it reappeared for a few months with an area of 12 km² (Wang et al. 2002). In the course of decreasing runoff reaching Ejina County, soil salinisation increased in parts of the county (Qi & Cai 2007). Groundwater levels dropped from 0.5 – 1.3 m in the 1940s to 3 – 6 m in the 1990s (Guo et al. 2009). However, the runoff from the Qilian Mountains has not changed significantly during the past 50 years despite climatic changes and shrinking glaciers as reported for other mountains in China and Central Asia (Jiang & Liu 2010).

In 2000, an integrated water resource management of the Heihe River Basin was established (Guo et al. 2009). In the frame of this integrated water resource management a water allocation plan between middle and lower reaches, i.e. between Zhangye and downstream of Zhangye, was adopted, which is described in detail in Chapter 4. Today, the amount of water that Ejina receives lies above the annual evapotranspiration of the whole cropland and riparian ecosystems within Ejina. More water was led into the eastern river branch of the Heihe compared to the western branch so that the reed and shrub vegetation around the East Juyanhai Lake started to recover (Guo et al. 2009).

2.3 Wuliangsuhai Lake and the Hetao Irrigation District

Wuliangsuhai Lake is a shallow wetland with an area of 293 km² located about 100 km west of the city of Baotou in Inner Mongolia (Yamian et al. 2012). More than half of the wetland is covered by *P. australis*. Wuliangsuhai Lake is a wetland in a dryland region. The mean annual precipitation ranges from 139 mm to 222 mm in the Hetao Irrigation District and neighbouring Wuliangsuhai Lake (Wang et al. 2004). Wuliangsuhai Lake receives water from the neighbouring Hetao Irrigation District. Thus, it is a representative example for the many wetlands in Central Asia, which are located, downstream of an oasis and are sustained by the drainage waters of those oases. Looking at the map of China, the Yellow River forms a great loop in the three provinces Ningxia, Inner Mongolia and Shanxi. The Yellow River flows in a northeast direction from Ningxia into Inner Mongolia. There, the Yellow River turns east for about 350 km. East of Baotou, the river turns south and flows from Inner Mongolia into Shanxi Province. In the curved area, where the Yellow River turns east in Inner Mongolia, a major river course, the Wujia River branches off from the Yellow River and goes back into the Yellow River, precisely, Wuliangsuhai Lake. Several river courses connect the Yellow River's mainstream and the Wujia River so that an inland delta with numerous wetlands are formed. At present, Wuliangsuhai Lake is the most eastern part of this inland delta (Wu et al. 2013; Fejes et al. 2008).

As all other rivers with their accompanying wetlands in Central Asia, this inland delta has been attracting people ever since. Agriculture is documented from the Han Dynasty (206 BC to 220 AD), and according to the strength of the ruling Chinese dynasties, it expanded during periods of strong leadership (e.g. Tang and Song Dynasties) and shrunk during periods of weak central power. This inland delta has also been an important region for Mongolian nomadic herders. During the end of the 19^{th} Century, under the Qing Dynasty, eight main irrigation channels were constructed, which laid the basis for the irrigation scheme of today in the Hetao Irrigation District. In 1923, the railroad from Beijing via Inner Mongolia to Lanzhou was constructed leading to an increased migration into Inner Mongolia and further land reclamation in the Hetao Irrigation District (Wu et al. 2013; Fejes et al. 2008). In 2005, the Hetao Irrigation District contained 5,860 km^2 of farmland, including a number of garden plots, which increased to 5,900 km^2 in 2010 (BLRB 2012). The water for the irrigation of the whole district is diverted from the Yellow River at the Sanshenggong Water Station in the south western tip of the Hetao Irrigation District into the central irrigation channel, which runs parallel to the Yellow River. From that channel, the water is further diverted through a network of 7,645 km of irrigation channels arranged around ten main channels. Parallel to the structure of the main irrigation channels, there is a network of 2,535 km of drainage channels. The central drainage water collector runs in the previous river course of the Wujia River (Figure 2). This central drainage collector enters into the northern part of Wuliangsuhai Lake and is the main water source for the lake. From 1960 to 1980, annually 4–5 km^3 water were diverted from the Yellow River into the Hetao Irrigation District (Yamian et al. 2012). This amount of water increased to 5-6 km^3 after 1980 until today. From the Hetao Irrigation District, 0.1–1 km^3 water was drained into Wuliangsuhai Lake from 1960 to 1980. After 1980, this amount of water increased to 0.5–1.2 km^3 per year. The annual water intake of the Hetao Irrigation District and the runoff into Wuliangsuhai Lake are further explored in Chapter 10. The main crops planted in the Hetao Irrigation District are rape, wheat, corn and sunflower on 1,720 km^2, 1,630 km^2, 1,510 km^2 and 1,290 km^2, respectively. Further crops are sugar beet, melons and tomatoes.

Wuliangsuhai Lake, unlike the terminal lakes of the Heihe, has never fallen dry. It continuously receives water. As the water source for Wuliangsuhai Lake is drainage water from the Hetao Irrigation District, it receives an annual load of 2,292.65 t of total nitrogen and 247.36 t of total phosphorus from agriculture, industry and households in the Hetao Irrigation District (BCPG 2010). Therefore, Wuliangsuhai Lake suffers from eutrophication. It is a showcase for a wetland downstream of an intensively agricultural cropped oasis. The core issue of Wuliangsuhai Lake, therefore, is water quality rather than water quantity.

Wuliangsuhai Lake formed in a shallow depression as part of the previous inland delta of the Yellow River. Today, its area is between 293 km^2 and 310 km^2, depending on the water level. The average water depth is 1 m with a maximum water depth of 4 m. The water volume ranges between 0.25 and 0.3 km^3 (Yamian et al. 2012; Liu et al. 2007b; Fejes et al. 2008). The climate is arid and extremely continental with an annual precipitation of 222 mm, a minimum temperature of -38 °C in January, and a maximum temperature of 38 °C in July. The mean annual temperature is 7.3 °C. Due to the low winter temperatures, the lake is frozen from November to April for 152 days on average (Yamian et al. 2012; Faafeng et al. 2008; Fejes et al. 2008). Due to the nitrogen and phosphorus input brought into Wuliangsuhai Lake by the drainage waters from the Hetao Irrigation District, the lake suffers from severe eutrophication and, accordingly, deterioration of water quality.

The dominant vegetation in Wuliangsuhai Lake are reed beds from mainly *P. australis* and to a limited extent from *Typha latifolia* (Zeng et al. 2012). Those reed beds cover 188 km^2, more than half, of the lake (Shang et al. 2011). Enhanced by eutrophication, the reed bed area increased from 165 km^2

in 1986 to 188 km² to date. Along with the decreasing water quality, the amount and area of *Potamogeton*-dominated submerged vegetation and algae increased. The biomass from submerged vegetation and algae deposits on the sea floor every autumn, which gradually reduces the water volume of the lake. In addition, biomass from *P. australis* and *T. latifolia*, if not harvested, tend to build up, creating deposits and contributive masses that gradually reduce the lake's overall water volume. Recently, the annual rate of deposition is 2 cm (Zeng et al. 2012).

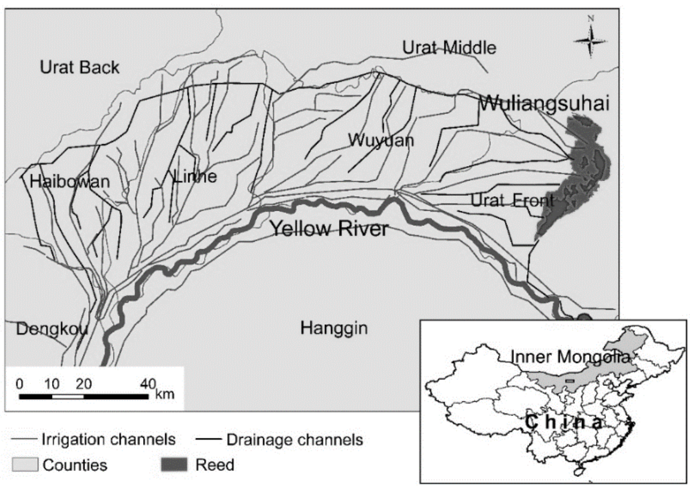

Figure 2 – Map of the Hetao Irrigation District and location of Wuliangsuhai Lake (Liu 1997).

Wuliangsuhai Lake serves as water storage reservoir for the Yellow River by discharging water into the Yellow River during the low water period in spring. Therefore, the water volume available for water storage is of importance for the whole Yellow River basin downstream of Wuliangsuhai Lake. In addition, the quality of the water released from Wuliangsuhai Lake into the Yellow River is of importance for water users downstream (Wu et al. 2013). Furthermore, the lake and its reed beds provide habitat for migratory and breeding birds (Faafeng et al. 2008). In 1993, Wuliangsuhai Lake became a provincial nature reserve (Zeng et al. 2012).

In Wuliangsuhai Lake, reed plays a crucial role for regulating the water quality. *P. australis* has a high ability to purify water as investigated in Chapter 6. Harvesting reed, *Potamogeton*, and algae biomass also may remove nutrients from Wuliangsuhai Lake (Frick et al. 2011). *P. australis* and *T. latifolia* are harvested in winter, when harvesters can access the reed easily on the frozen lake. This biomass is sold as raw material for paper production as described and analysed in Chapter 8. In addition, more options for reed biomass utilisation are explored in Chapter 8 (Köbbing et al. 2013). The option to use reed biomass as energy source is analysed in Chapter 7 and Patuzzi et al. (2013), including reed biomass as feedstock for biogas production. Biogas production as well as utilisation of reed biomass as green manure require reed harvest during summer, which would enhance nutrient removal compared to winter harvest, but is less convenient. The approaches to tackle the eutrophication of Wuliangsuhai Lake cannot be restricted to measures within the lake. There is a holistic need to include the diversity of agricultural cropping systems, especially from varying fertiliser applications currently put in place throughout whole of the Hetao Irrigation District. Such a holistic approach is explored in Chapter 10 by way of scenario alternatives, opening up pathways for sustainability and management-based objectives.

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