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THEMATIC ISSUE

Water resources and their management in central Asia in the early twenty first century: status, challenges and future prospects

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Abstract Large parts of Central Asia are characterized by a semiarid to arid climate. Therefore, areas close to shallow groundwater, rivers and lakes are characterized by unique water-dependent ecosystems and human societies which have developed over millennia in close interaction with the naturally limited water resources. In the early 21st century, global climate change, population growth, river damming, large-scale water abstractions and rising levels of pollution exert multiple pressures on the region's water resources, aquatic and terrestrial ecosystems at historically high levels. Water scarcity threatens the livelihood of populations locally and in transboundary settings by a growing competition over a limited resource. This context is of particular importance since all major rivers of the region cross at least one international border. The complexity and character of water-related challenges in the region mean that management approaches need to be integrative, taking into account the natural resource basis, environmental limits and the socio-cultural and geopolitical dimension. This paper frames the thematic issue of Environmental Earth Sciences and provides a comprehensive overview about the current state of knowledge about water resources and their management in Central Asia. There is a focus on case studies looking at the Selenga–Baikal–Angara Basin, the Lake Aral Basin including the Syr Darya and Amu Darya river systems, the Tarim and the Illi River Basins. Aiming to be an up-to-date interdisciplinary scientific reference on the region's water-related challenges, this thematic issue gives theoretical and practical insights into solutions and best practice examples of water management.

Keywords Central Asia · Hydrology · Water quality · Aquatic ecosystems · Water resources management · Transboundary rivers/lakes

Introduction

Both in international and Russian language literature, there is no uniform usage of the term Central Asia. While Soviet geographers normally referred to Uzbekistan, Kyrgyzstan, Turkmenistan, Tajikistan and sometimes Kazakhstan as "Middle Asia" (Средняя Азия), the term "Central Asia" (Центральная Азия) is often used in a wider sense. Besides the formerly Soviet "-stans", Central Asia may encompass Mongolia, Western China, Russian Siberia, and the northern parts of Iran, Afghanistan, Pakistan and India (Cowan et al. 2007). Because of the region's continental location and thus naturally limited water resources, water management has been important since historical times (Dukhovny and Galina 2008). In fact, intelligent water management was one of the key prerequisites for the emergence of early civilizations in the region (Opp 2007a). Given the high relevance of water for social and economic development in

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the region, physico-geographical definition of Central Asia in terms of delineation by river basin boundaries rather than state borders is a meaningful approach (Malsy et al. 2014).

Water in Central Asia

Central Asia has some of the highest degree of continentality in the world (Mannig et al. 2013), a fact which does not only lead to very large intra-annual temperature variations but which also naturally limits the region's water resources.

This not only results in comparatively sparse vegetation, but also in high sensitivity of grasslands and semi-deserts to precipitation anomalies (Gessner et al. 2013). Rivers are often associated with particular riparian ecosystems such as the 'tugai' vegetation around the Tarim River (Aishan et al. 2014).

Apart from specific studies, (long-term) environmental monitoring data in Central Asia is typically limited to a few sub-regions such as capital cities or centers of agriculture and industry. The Selenga River, the main tributary of Lake Baikal, is one case in point, with only 62 gaging and even fewer water quality monitoring stations in an area covering a basin of about 450,000 km^2 (Chalov et al. 2014). Moreover, in many parts of the region, meteorological and hydrological monitoring stations and routine surveillance programs have ceased to operate following the breakdown of the Soviet Union. This could particularly be observed in remote regions where data collection is relatively complicated and costly (Unger-Shayesteh et al. 2013a; Mannig et al. 2013). This situation is further complicated by restrictive data policies, particularly in the region's international river basins (Kundzewicz et al. 2014).

In the context of water resources management, Central Asia is a region of extremes. The region is home to extremely overused river systems on the one side, as is illustrated by regions with intensive agriculture (such as the Aral Sea Basin) and several river basins surrounding national capitals (Opp 2007a; Aus der Beek et al. 2011; Malsy et al. 2014). On the other hand, Central Asia is home to some of the most pristine rivers in the world, and to the oldest, largest and least-polluted freshwater lake in the world, Lake Baikal (Opp 2007b; Menzel et al. 2011).

Massive water withdrawals from the Amu Darya and Syr Darya Rivers used for irrigation have led to the progressive desiccation of the Aral Sea since the 1960s and attracted global attention to water-related problems in Central Asia (Cretaux et al. 2013; Schlüter et al. 2013; Mannig et al. 2013). The intentional abstraction of surface water in a quantitative dimension that (predictably) led to a far-reaching environmental degradation and loss of Central Asia's largest lake became known world wide as the "Aral Sea Syndrome" (Opp 2007a). Today, more than 90 % of the annually available freshwater in the Aral Sea Basin is used for irrigation of crops on around 8 million ha of land (Roll et al. 2005). Despite the regional water scarcity, crops with high irrigation requirements such as cotton predominate and irrigation efficiencies are often low (Conrad et al. 2013). Global climate change is another factor contributing to the shrinkage of the Aral Sea since it reduces the runoff in the Amu Darya and Syr Darya river systems (Jarsjö et al. 2012; Aus der Beek et al. 2012). Large parts of the former lake have been transformed into a new desert, the "Aral-kum". The consequences of this irreversible process have been manifold: the climate has become more continental; the lake and riverine ecosystems, as well as surrounding terrestrial ecosystems have degraded severely; local fishery and the fish-processing industry have diminished or declined; and infant mortality has risen to the highest level in Central Asia (Opp 2007a).

About this thematic issue

For the wider Central Asian region, this thematic issue intends to provide a multidisciplinary perspective on science-based analyses of water-related challenges and potential solutions. Even though there are inherent difficulties in integrating the results of a large number of independent and methodologically diverse studies, the thematic issue contains a unique compilation of both original data and reviews for a region in which data are scarce and/or inaccessible to the international research community.

Today's most pressing challenges are often related to a combination of manmade water shortages and water pollution, putting at risk both the environment and the future socioeconomic development of affected regions. The high number of transboundary rivers in Central Asian region (Chalov et al. 2013) results in an even higher probability of water-related conflicts. On top, Central Asia is expected to be one of the "hot spots" of climate change (Unger-Shayesteh et al. 2013b) with an increasing vulnerability of the water resources in the near future.

Following this, in the present review we provide an integrative picture of the state of the -art regarding the following water-related issues in Central Asia:

1. Water availability
2. Water use
3. Water quality
4. Aquatic, riparian and oasis ecosystems
5. Water resources management
6. Geopolitical perspectives on transboundary water resources

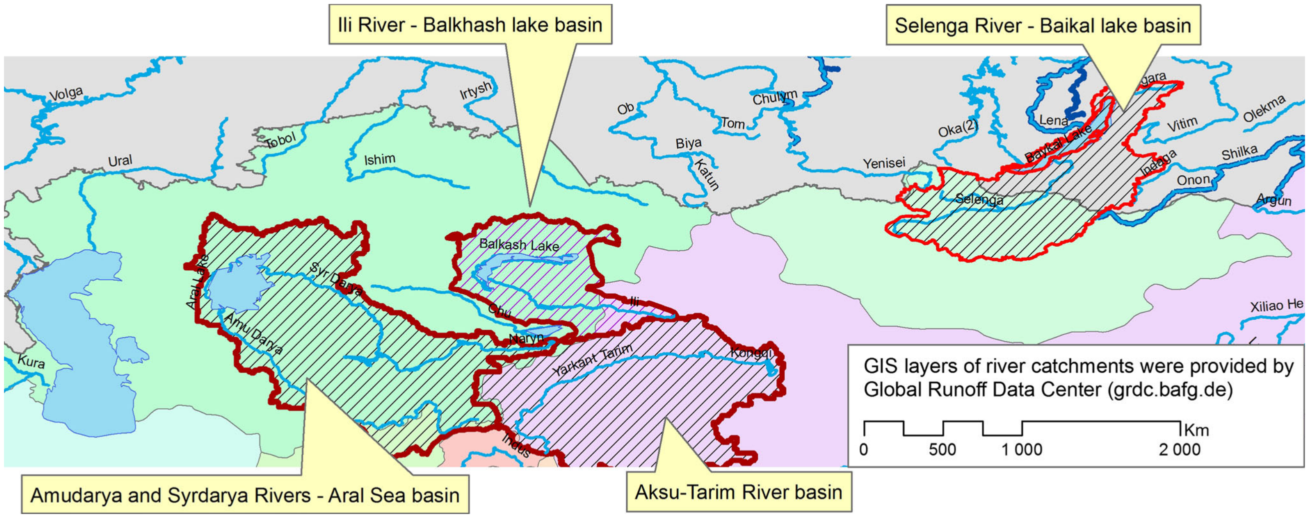

Fig. 1 Drainage basins covered in the thematic issue

Figure 1 illustrates the location and spatial extent of the drainage basins covered by the papers in this thematic issue. Table 1 provides a basin-wise overview of the topics covered.

Water availability

A highly continental, relatively dry climate with large temperature amplitudes (about −40 °C to +40 °C) is typical for Central Asia (Malsy et al. 2012). Consequently, the water resources which feed large parts of the region originate from headwater areas in high-mountain zones, such as the Pamir and Tien Shan (Unger-Shayesteh et al. 2013a; Savoskul and Smakhtin 2013). In these mountainous regions, both glaciers and snow pack provide an intermediate storage of water resources. While glaciers store water over long periods, thereby balancing seasonal and inter-annual water availability, both glaciers and the seasonal snow pack release water during the summer season when it is most needed for agricultural production (Unger-Shayesteh et al. 2013a; Kriegel et al. 2013). In a global perspective, Central Asia is one of the regions with the highest proportion of discharge formed in mountain areas (Viviroli and Weingartner 2004). Moreover, the relative contribution of glacier melt to total discharge is particularly high in Central Asia where mountainous areas are surrounded by dry lowlands (Hagg et al. 2013a).

Despite a relative shortage of water in large parts of Central Asia, the region is also home of the largest freshwater lake in the world: Lake Baikal contains about 20 % of the available fresh surface water in the world, and contains the largest aquatic biodiversity of any inland surface water with more than 2,500 species. About 60 % of the animal and 15 % of the plant species are endemic (Opp 2007b).

The inhabitants of Central Asia are fairly well provided with water, including on average about 4,000 m^3 of surface water per person annually (Shiklomanov and Rodda 2003). Nevertheless, water resources assessment has become a high political priority in the Central Asia because of an uneven distribution of these resources and a growing competition between up- and downstream users (Janusz-Pawletta 2014; Chalov et al. 2013). While available water resources are decreasing in many parts of Central Asia, the region's population is predicted to grow by an estimated 40 % between 2000 and 2025 (Valentini et al. 2004).

Central Asia is considered a "hot spot" of climate change which is expected to have serious consequences for the region's water resources (Unger-Shayesteh et al. 2013b). According to the IPCC's Fourth Assessment Report, Central Asian drylands are particularly vulnerable to climate change impacts, with reduced water availability, loss of biodiversity and land degradation as key consequences (IPCC 2007b). Meteorological data series available since the end of the 19th century show a steady trend of increasing temperatures throughout Central Asia (Lioubimtseva and Henebry 2009), which is predicted to continue in the 21st century at a rate which is above the average global increase (IPCC 2007a; Mannig et al. 2013). For the region of former Soviet Central Asia, Unger-Shayesteh et al. 2013b have calculated mean warming rates between 0.18 and 0.42 K per decade during the last 50–60 years. The highest increases could be observed in Siberia (IPCC 2007b).

This warming trend will not only result in higher evaporation (Karthe et al. 2014), but also a very significant retreat of glaciers (WWAP 2012a; IPCC 2007b) which

Table 1 Drainage basins and their coverage in the thematic issue

Basin	Topics
Tarim river basin	Water availability
	Changes in climate and seasonal river discharge in the Aksu River Basin (Kundzewicz et al. 2014)
	Water use
	Agricultural development and water use (Feike et al. 2014)
	Aquatic, Oasis and Riparian Ecology
	Eco-morphological response of floodplain vegetation to water abstractions (Aishan et al. 2014)
	Riparian vegetation and groundwater table fluctuations (Chen et al. 2013)
	Water Management
	Effectiveness of water pricing to promote water conservation (Mamitimin et al. 2014)
	Suitable scales of oases in the Keriya River Basin (Lei et al. 2014)
Selenga–Baikal–Angara basin	Water availability
	Modeling of water availability in the Kharaa River Basin (Hülsmann et al. 2014)
	Evapotranspiration dynamics in steppe and shrubland, Kharaa River Basin (Minderlein and Menzel 2014)
	Identification of water sources by advanced hydrograph separation for Eastern Siberian streams (Semenov et al. 2014)
	Water use
	Water storage and hydroenergy potentials on the Angara (Jaguś et al. 2014)
	Water quality
	Groundwater quality in the Kharaa subbasin (Hofmann et al.)
	Arsenic occurrence and sources in ground, surface, waste and drinking water in Northern Mongolia (Pfeiffer et al. 2014)
	Spatio-temporal variation of suspended sediment loads in the Selenga river system (Chalov et al. 2014)
	Water management
	Development of a science-based river basin management for the Kharaa River Basin (Karthe et al. 2014)
	Impact of land use on erosion and water management in the Kharaa river basin (Priess et al. 2014)
	Decision support model for integrated urban water management: case study of Darkhan, Mongolia (Rost et al.)
Aral sea basin	Water availability
	Multiscale environmental changes and its impact on water resources in the Aral Sea Basin (Lioubimtseva 2014)
	Water use
	Water consumption and its impacts in the Amu Darya Basin (Thevs et al. 2014)
	Water quality
	Water quality gradients along the Zarafshan river (Groll et al. 2013)
	Water management
	Decentralization and post-soviet transition of irrigation management in the Aryz River Basin (Zinzani 2014)
	Geopolitical perspectives on transboundary water resources
	Conflict potentials due to water pollution (Groll et al. 2013)
Ili river basin	Aquatic, oasis and floodplain ecology
	Climate change and invasive alien species in the Ili River Basin (Xu 2014)
Topical papers	Water availability
	Modeling precipitation and water availability in Central Asia (Malsy et al. 2014)
	Hydroclimatological hazards in the Nepal Himalayas (Fort 2014)
	Water use
	Water use and development scenarios for Hetao irrigation area, China (Kerschbaumer et al. 2014)
	Aquatic, oasis and floodplain ecology
	Macroinvertebrate communities in Mongolian headwater streams (Narangarvuu et al. 2013)
	Water management
	History of water management in Central Asia (Abdullaev and Rakhmatullaev 2013)
	Drinking water supply management in rural Kyrgyzstan (Rost et al. 2014a)
	Water resources management to combat desertification in Xinjiang, China (Li et al. 2014)
	Geopolitical perspectives on transboundary water resources
	Legal challenges for transboundary water management in Central Asia (Janusz-Pawletta 2014)
	Water security and capacity building in Central Asia (Abdolvand et al. 2014)

causes complex changes to the hydrological regimes of river systems originating in high-mountain zones (Chen et al. 2007; Unger-Shayesteh et al. 2013a). Most studies agree that the largest increases in temperatures occur during the winter months, shortening the period with temperatures suitable for snow cover and ice formation while extending the period of snow and ice melt. This process may be self-reinforcing due to a reduced snow-albedo feedback (Unger-Shayesteh et al. 2013a). Using the REMO and ECHAM models, Mannig et al. 2013 have simulated an increase of winter temperatures ranging between 2 K and more than 8 K by the end of the 21st century (2071–2100 vs. 1971–2000).

During recent decades, Central Asian glaciers have shown predominantly negative mass balances. While many small glaciers have disappeared completely, larger glaciers have separated into several branches and retreated to higher elevations (Unger-Shayesteh et al. 2013a). For a model region located in the Central Tien Shan, a decrease in glacier area of 23.4 % was observed between 1977 and 2007 (Hagg et al. 2013b; Kriegel et al. 2013). For the Panj, the main tributary of the Amu Darya, glacier extent losses of 36–45 % are likely by 2050 when assuming a moderate (+2.1 K) to strong (+3.2 K) warming trend (Hagg et al. 2013a). Measurements in boreholes in Central Asia show that much of the permafrost is currently at temperatures close to 0° C and very sensitive to warming trends (Zhao et al. 2010).

Rising temperatures are particularly relevant for regions relying almost solely glacier melt water. In Central Asia, the discharge of some major rivers has increased due to glacier mass losses (Unger-Shayesteh et al. 2013a; Hagg et al. 2013b). While the annual mean discharge could remain stable for some river basins until 2050 (Hagg et al. 2013a), reductions of up to 50 % are expected in some catchments (Groll et al. 2013). Moreover, even for river basins with stable annual discharge, glacier mass losses are likely to cause a runoff reduction during the summer months (Hagg et al. 2013a), thus decreasing irrigation capacities when they are most needed.

An observed increase in precipitation during the 20th century is likely to reverse into a slight decline in the 21st century (about −3 % by 2080–2099 as compared to 1980–1999) and a significantly higher risk of very dry spring, summer and autumn seasons (IPCC 2007a; Gessner et al. 2013). However, global climate models are known to perform poorly in the region and tend to overestimate precipitation (IPCC 2007a; Malsy et al. 2013; Mannig et al. 2013). In contrast to temperature, both observational studies and projections come to diverse findings on precipitation change in the region (Unger-Shayesteh et al. 2013a).

Until recently, regional climate models were missing and the hydrological relevance of the cryosphere (long-term glacier and short-term snow storage) was only poorly incorporated into them (Unger-Shayesteh et al. 2013b).

In this thematic issue, Malsy et al. (2014) discuss the feasibility of using large-scale climate and precipitation data sets (CRU, GPCC, WATCH forcing data and Aphrodite) to model water resources in Central Asia. Using the Water GAP model, they conclude that depending on the data set used, there are considerable differences in regional water availability predictions, with GPCC and Aphrodite producing the most realistic results for those regions where sufficient validation data from gaging stations exist. However, model validation was found to be extremely difficult in regions with a low station density, such as mountainous headwater zones and the more arid southern part of Central Asia. Kundzewicz et al. (2014) analyzed changes in climate and discharge for the Aksu river, the principal tributary to Tarim river. Between the 1950s and mid-2000s, they observed a statistically significant temperature increase of 0.8–1 K and a slight increase in precipitation. Since the flow regime of the Aksu is dominated by snow and glacier melt, changes in discharge were found to be related more to anomalies of temperature than of precipitation.

Several studies deal with water sources and availability in the Selenga–Baikal–Angara Basin. Hülsmann et al. (2014) analyzed water balance components and hydrograph pattern in the Kharaa River Basin in Northern Mongolia to identify flow generating processes. Besides large spatial variations (but limited data) and very high evapotranspiration rates, the authors identified subarctic processes as a key challenge for representation in commonly used hydrological models. These include both river icings and frozen subsurfaces (with regard to seasonal freezing and discontinuous permafrost), which are relevant for (a) inter-seasonal redistribution of water resources and (b) hydraulic characteristics of the soil. In the same river basin, Minderlein and Menzel (2014) compared the evaporation and energy balance dynamics of mountainous steppe and shrubland sites of the forest–steppe ecotone that is typical for mountain areas of Northern Mongolia and Southern Siberia. In this region, southerly exposed slopes are characterized by very low soil moisture and typically covered by steppe, whereas dense taiga forests on northerly exposed slopes allow the persistence of ecosystem protected but discontinuous permafrost which is an important source of soil water during summer drought periods. Shrub vegetation is mostly found in the riverine floodplains. According to the authors' findings, there is only negligible freshwater generation in sparsely vegetated steppe areas, whereas shrubland and taiga play an important for water availability in further downstream areas. Consequently, they consider their protection as a high priority in the context of integrated water resources management (IWRM). Semenov and Zimnik (2014) describe an advanced hydrograph separation technique to identify sources of stream water in the Lake Baikal and Angara River Basin. The authors argue that in-stream chemistry data taking into account the DOC vs. basic cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) ratio are suitable and cost-effective alternative to alternative approaches differentiating between hydrologically distinct sources.

For the northern Himalayas, the paper by Fort (2014) discusses impacts of climate change on a high-altitude valley. The author concludes that warming will affect both glaciation and permafrost, leading to reduced glacier melt-related runoff generation and increasing ground instabilities and mass movements.

For the Aral Sea Basin, the paper by Lioubimtseva (2014) discusses the human vulnerability to environmental changes at the global, regional and local scale. For three topics (water availability, food security, human health) the author analyzes the exposure, sensitivity and adaptive capacity of local populations (Lioubimtseva 2014).

Water use

Central Asia is one of the most ancient areas of irrigated agriculture (Abdullaev and Rakhmatullaev 2013). Today, about 90 % of all surface and ground water abstractions are used by the agricultural sector, which is more than in any other region of the world (WWAP 2012b; Unger-Shayesteh et al. 2013b). In the region of former Soviet Central Asia, large-scale dams and reservoirs have been built since the 1950/60s and several rivers diverted to provide water for irrigation (Unger-Shayesteh et al. 2013b). Moreover, the agricultural sector is the key driver of (often large-scale) land cover change in the region. Whereas the major trend in the last century was an extension of agricultural land, the collapse of the Soviet Union led to a sudden de-intensification in the early 1990s (Lioubimtseva and Henebry 2009). This trend has partially reversed again during the last decade and goes along with increases in irrigated agriculture (Malsy et al. 2014; Thevs et al. 2013; Karthe et al. 2011). Irrigation in semiarid to arid settings lead to the desiccation of rivers and lakes (Han et al. 2011; Opp 2007a; Thevs et al. 2013; Feike et al. 2014), soil and water salinization (WWAP 2012a; Thevs et al. 2013 and Kuba et al. 2013) and facilitate erosion and the influx of fine sediments, nutrients and agrochemicals into surface water bodies (WWAP 2012a; Chalov et al. 2013). Such pressures do not only affect aquatic ecosystems but also terrestrial floodplain ecosystems (Kuba et al. 2013).

While during the 1990s, food production and the daily per capita calorie intake declined in Central Asia, this trend reversed around the year 2000 and resulted in a higher per capita water footprint for food production. The growing water demand due to changes in dietary habits is exacerbated by population growth, which is currently about 1.1 % per year (Djanibekov et al. 2013). Moreover, exports of cotton and food crops mean that the virtual water balance of many Central Asian nations is negative. In case of Uzbekistan, for example, virtual water exports amount to 28.3 billion m^3/year as opposed to imports of 7.6 m^3/year (Rudenko et al. 2013).

In this thematic issue, Feike et al. (2014) analyze the development of water usage in the Chinese parts of the upper Tarim River Basin, a region where the population and agricultural land use have increased considerably since the late 1980s, leading to a reduced water availability and agricultural production further downstream. Thevs et al. (2014) investigated the water consumption of agriculture (wheat, cotton, rice) and natural ecosystems on the Amu Darya River in Turkmenistan. The authors concluded that (a) there is a considerable disparity between actual crop water consumption and water withdrawals, pointing to water losses due to inefficient irrigation infrastructures and methods, (b) cotton and rice have comparatively high crop water consumptions, even though lower than expected evaporation estimates indicate that these crops are grown under water-stressed conditions.

Kerschbaumer et al. discuss development scenarios for the Hetao irrigation area in Inner Mongolia (China) and their impact on water quantity and quality in Wuliangsuhai Lake, which is mostly fed by agricultural wastewater and which provides a large range of ecosystem services in this highly arid area.

Water quality

Regions that are relatively less well-endowed with water, as is the case in continental Central Asia, are more severely affected by water quality deterioration than more humid regions (WWAP 2012b). In Central Asia, where water resources are relatively scarce, water quality impairments by salts, agrochemicals, organic pollutants and heavy metals are frequent in the downstream parts of most river catchments (Groll et al. 2013). Alterations of the hydrology often reinforce such changes in hydrogeochemistry. A case in point is the basin of the Amu Darya and Syr Darya rivers and the Aral Sea. Even Lake Baikal has come under pressure from pollution by heavy metals as well as toxic and persistent organic pollutants (Chalov et al. 2014 Changes in water quality are typically caused by the release of heavy metals associated with mining and ore excavation.

Besides impacts from the agricultural sector, important stressors for surface water quality include improper waste and sewage disposals in the municipal and industrial sectors (Darracq and Destouni 2005; Evans and Webster 2008; WWAP 2012a) and increasingly from mining of the various geogenic resources in the region (Malmström et al. 2008; Hofmann et al. 2010; Thorslund et al. 2012; Chalov et al. 2013).

In this thematic issue, Groll et al. (2013) address water quality-related challenges in the transboundary Zarafshan River Basin which is shared by Tajikistan and Uzbekistan. Due to extensive water withdrawals, the Zarafshan no longer reaches the Amu Darya since 1957. Moreover, elevated temperatures, reduced oxygen saturation, high nutrient loads and a contamination with copper, chromates and phenols lead to a massive degradation of the river's ecosystem in its downstream section (Groll et al. 2013).

Several case studies address water quality issues in the Selenga–Baikal Basin. Chalov et al. (2014) investigated sediment and pollution loads along the Selenga River and its tributaries, several of which are impacted by mining activities. For the Selenga River Delta, which acts as a "natural filter" before the Selenga discharges into Lake Baikal, the authors calculated an average sediment load of 2.51 Mt/year. However, their modeling results show a decreasing trend, which is probably related to a relatively long-term low water period and the abandonment of agricultural land in the Russian part of the Selenga River Basin since the 1990s.

For northern Mongolia, Pfeiffer et al. investigated arsenic (As) concentrations in ground, surface and drinking water and found them to exceed WHO guidelines to a degree and extent that was previously unknown. They identified mining activities and the combustion of coal and wet deposition of ash at power plants as the key sources of this contamination.

Hofmann et al. (2014) carried a ground water survey for the Kharaa River Basin in Mongolia. The authors found that ground water extractions even in the most urbanized areas do not (yet) exceed groundwater recharge, but detected growing problems related to groundwater contamination, which they attributed to mining activities and poor treatment of industrial and domestic wastewater—but partially also to natural (geogenic) sources.

Aquatic, riparian and oasis ecosystems

The aquatic ecosystems of Central Asia are the result of regionally diverse climatic, hydrological and hydro-geological conditions. A unique characteristic is the connections with one of the world's largest mountain systems that include the Caucasus, Pamir-Alay, Hindu Kush and Altai. Their glaciers and snow packages feed large watersheds and provide water for the natural ecosystems over far distances. Very often, this is also true at a more regional scale where mountain areas form the "water towers of river catchments", as they provide over-proportional runoff to river networks. An example is the medium-sized Kharaa river in Mongolia (catchment area 15,000 km^2), where approximately 20 % of the catchment area covered with mountain forests provide 2/3 of the annual runoff of the entire river system (Menzel et al. 2011). However, a considerable part of the aquatic ecosystems is located in foothill areas and adjacent valleys, which at the same time have been the historic nuclei of human settlements for many centuries.

The anthropogenic development and irrigation of these plain areas have transformed the natural aquatic ecosystems in many ways. A large number of aquatic ecosystems including springs, running waters, floodplains and lakes have completely disappeared in the recent past (Dukhovny et al. 2008). However, human influence has also created a large number of manmade aquatic ecosystems such as irrigation networks, channels, impoundments and reservoirs. Some of these have connected naturally distinct watersheds, leading to the expansion of alien and invasive species (Dukhovny et al. 2008).

The physical zoning in altitude and the resulting climatic zoning of temperatures and precipitation are major determinants of the regional ecosystem types. Although aquatic biota and communities have adapted to the harsh environmental conditions, e.g., via life cycles (Avlyush et al. 2013) or migration (Mercado-Silva et al. 2008), many of them have to be considered as being sensitive or vulnerable (Narangarvuu et al. 2014). Another unique character is closed basins of large lakes including the Aral Sea, Lake Balkhash and Lake Issyk-Kul that have no connection to marine environments and their flora and fauna are characterized by high biodiversity, considerable productivity and high degrees of endemism across taxonomic groups (Feng et al. 2013). These communities are particularly sensitive against invasive species (Xu et al. 2014).

The large variety of aquatic ecosystems including extensive river networks, floodplains, riparian ecotones and large numbers of stagnant waters of various sizes are characterized by abiotically determined ecosystem templates. Temporary running waters are found across different stream orders, depending on climate, hydrology and geological setting within the individual catchments. The river networks drain into a wide range of basins including the Central Asian Inland Basin and different marine environments (Arctic Ocean and Pacific Ocean). Numerous rivers networks that have their sources in the mountainous regions may be seen as "waters towers" of the landscape with high precipitation and runoff generation. They transport water over far distances and into dry regions, deserts and landlocked catchments. In the Central Asian deserts, the floodplain forests (Tugai) along the large river systems like the Amu Darya and Syr Darya form a remarkable extrazonal vegetation with a high biodiversity of flora and fauna and a regional concentration of timber (dominated by *Populus euphratica*). Therefore, these floodplains and their forests provide a wide range of ecosystem services for humans in those regions (Thevs et al. 2012). Another important group of azonal ecosystems is oases that occur in many dry regions across Central Asia (White et al. 2000).

The lakes and stagnant waters of Central Asia are of different origin (e.g., formed by glaciation in land depressions, build in river systems with natural barrier or tectonically). Some of them are very large (e.g., Aral Sea, Lake Balkhash and Lake Issyk-Kul) and old, including the world's oldest and deepest freshwater lake, Lake Baikal in Siberian Russia (age: 25 mill. years and max. depth 1642 m). Many other stagnant waters have been formed by glaciation in land depressions or have been built in river systems with natural barriers. As a result of this diverse evolutionary history endemism plays a major role in shaping the regional patterns of aquatic communities. At larger scales the biodiversity is also influenced by migration, e.g., of a large variety of birds along rivers and with many wetlands and lakes as migratory stopovers (Schielzeth et al. 2010) and for migratory fish (Mercado-Silva et al. (2008).

In arid regions like Central Asia, changes in temperature, precipitation and hydrology have a very direct impact on the vitality and functioning of terrestrial ecosystems as they modify the principal abiotic templates of the ecosytems (Gessner et al. 2013; Schlüter et al. 2013).

In this thematic issue, Aishan et al. (2014) and Chen et al. (2013) show that massive water withdrawals and the construction of a reservoir first led to a total desiccation of the Tarim River's downstream section of 321 km since 1972, which increased to up to 428 km in the 1990s. This led to considerable changes in the lower Tarim's natural floodplain vegetation and increased wind erosion. Based on different data sets, the authors of the two studies assess the success of ecologically motivated water diversions into the lower Tarim which have been carried out since 2000. Besides raising the groundwater table, these flooding have helped to restore riverine floodplain forests.

Xu et al. (2014) modeled the potential future distribution of invasive species in the upper Ili River Basin. Their analyses show that key determinants of the underlying habitat modifications are changes in the mean temperatures of the cold and wet seasons, and changes in the precipitation of the driest month and the dry season in general.

Narangarvuu et al. (2013) in this issue carried out an extensive study of first-, second- and third-order streams of 80 rivers selected from the three main watersheds of Mongolia (Arctic Ocean Basin (AOB), Pacific Ocean Basin (POB) and Central Asian Internal Basin (CAIB)). They could show a remarkable biodiversity of Ephemeroptera, Plecoptera and Trichoptera (EPT) assemblages in the headwater streams of their study regions with significant differences between basins in taxon richness (POB > AOB > CAIB) and EPT abundance (highest in CAIB). Results of statistical analysis suggested that within the catchments altitude, dissolved oxygen, stream order and stream width were the most important factors explaining the variability in EPT larval distribution.

Water and land management

Despite some criticism related to its broadness and relative vagueness, integrated water resources management (IWRM) is currently the most widely accepted general framework for water management at the global level in general and for developing and transition countries in particular (Heldt 2014; Borchardt et al. 2013). According to Global Water Partnership, IWRM is "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP-TAC 2000). A key prerequisite for the operationalization of the IWRM concept is a transdisciplinary assessment of the environmental and socioeconomic conditions in regional context (Borchardt et al. 2013). IWRM thereby has to consider both human resource use and ecosystem protection. While many stressors are relevant for both human water security and the environment (e.g., chemical water pollution), some processes have both positive and negative effects. Reservoirs, for example, often have impacts on aquatic ecology and biodiversity, while at the same time providing ecosystem services for human needs. The invasion of a water body with non-native species, on the other hand, may threaten aquatic biodiversity but not necessarily bear consequences for water security (Vörösmarty et al. 2010).

A common problem in the context of river basin management is the spatial mismatch of administrative areas and river catchments (Xu et al. 2008). This often implies that management-relevant data are not available at river basin (and sub-basin) scale, and that management decisions are made at hydrologically unsuitable spatial levels. Moreover, water governance structures in Central Asia are often characterized by a multitude of institutions without clear mandates, lack of implementation capacity and financial resources constrain (Horlemann and Dombrowsky 2012; Karthe et al. 2011). Changes in the political geography of the region which are related to the dissolution of the Soviet Union in 1989 created additional challenges with regard to water resources management, including a much larger conflict potential in transboundary river basins than before

(WWAP 2012a; Chalov et al. 2013; Janusz-Pawletta and Yodalieva 2013).

In this thematic issue, Abdullaev and Rakhmatullaev (2013) discuss the transformation of water management in Central Asia from a historical perspective. While small-scale community-based irrigation schemes were commonplace until the mid-19th century, the first, still relatively small-scale, inter-basin water transfer projects were realized during the second half of the 19th and early 20th century. State influence on the water sector increased during the 1920–1940s, when infrastructures were collectivized and nationalized. The hydraulic mission of the Soviet era (1940–1990s) saw the realization of mega projects. Finally, in the newly independent states after the collapse of the Soviet Union, some decentralization, more market orientation and the arrival of integrated approaches could be observed (Abdullaev and Rakhmatullaev 2013). However, the breakdown of the Soviet Union also resulted in the disintegration of regional monitoring networks, a loss of knowledge in water management and an increased potential for international water conflicts (Groll et al., this issue). The paper by Zinzani (2014) addresses the transfer of irrigation management to water user associations (WUAs) in the mesoscale Arys River Basin, South Kazakhstan, in the context of sociopolitical and economic transformation following the disintegration of the Soviet Union. In different districts of South Kazakhstan province, WUAs faced similar problems. Typical challenges were related to budgetary restrictions (sometimes preventing maintenance and payment of salaries), the shift of responsibilities from district water departments to WUAs, and undemocratic structures (no election of leaders) preventing acceptance and participation. Differences were found with regard to staff who were either transferred from former water departments to WUAs (typically experienced but sometimes reluctant to implement changes) or newly hired (and often inexperienced). A frequent fluctuation of staff was identified as another problem. In fact, some WUAs have in the meanwhile been dissolved (Zinzani 2014). (Rost et al. 2014a) come to similar findings in their study on drinking water management in Central Kyrgyzstan, a region characterized by small and remote villages today and nomadic lifestyles in pre-Soviet times. The authors found WUAs often dissolved or existing only on paper, and identified village-level challenges for drinking water management that are typical for Central Kyrgyzstan. These include non-operational or non-existing drinking water supply infrastructures forcing people to organize their own supply, and nonexistent municipal sewage systems, forcing people to use private latrines that are typically in poor structural and hygienic conditions. Not surprisingly, outbreaks of diarrheal diseases including viral hepatitis are reported as consequences. A final problem discussed is that of low water fees that do not recover production and distribution costs, which is partly related to a low willingness to pay that is in turn a result of customer dissatisfaction with the services provided.

Despite all debates and problems related to it, water pricing can be an effective instrument to promote efficient water use and water conservation. For the Tarim Basin in northwestern China, Mamitimin et al. (2014) investigated farmers' reactions to a twofold increase in water prices and found that less than half of them opted for decisions leading to improved water efficiency, i.e., improving farm management, modernizing irrigation technologies or shifting to less water-demanding crops. More than half of the farmers either did not implement any changes, or worse, drilled wells to establish their own source of water (Mamitimin et al. 2014).

Several papers address the issue of water and land management in transdisciplinary, cross-sectoral and integrative contexts.

Focussing on the water–energy nexus, Jaguś et al. (2014) determined the storage capacities of the reservoirs in the Angara River Cascade, the largest water storage system in the world with a total water volume of more than 320 km^2. According to their study, the first dam, located near Irkutsk and 55 km downstream the Angara from Lake Baikal, has led to a volume increase of Lake Baikal and leads to an accumulation of contaminated sediments originating from the Selenga–Baikal system at its bottom. The three reservoirs further downstream cover a length of several 100 km each and have larger storage capacities than the Irkutsk Reservoir. All dams primarily serve the purpose of hydropower generation, which is expected to reach 66TWh per year in the near future (Jaguś et al. 2014).

Li et al. (2014) discuss the utilization of non-conventional water resources for desertification control in Xinjiang's Gobi Desert. According to the authors, conventional ground and surface water resources are used by industry, agriculture and domestic use to a degree that non-conventional resources may have to be used for other purposes including biological desertification control. Moisture stored in the sandy subsurface, flood and surface runoff and underground brackish water are discussed as non-conventional options. The authors conclude with the important caveat that even the utilization of such water resources for environmental objectives may induce alterations of local and regional hydrological cycles with consequences that are not yet well understood.

For the similarly arid Keriya River catchment, which forms a part of the Tarim River Basin, Lei et al. (2014) discuss the question of suitable scales of oases, trying to find a compromise between small scales restricting economic and social development potentials and unsustainably large scales. The authors take into account both 'natural oases' (i.e., oases with no or little anthropogenic influence on the environment) and 'artificial oases' (developed from natural oases or desert by long-term anthropogenic influence), for which they assume minimum water demands of 400 and 500 mm, respectively, and recommend a ratio of at least 6:4 (natural:artificial oases). On these grounds, they still see a limited development potential for the Keriya River Basin, provided that measures to improve water use efficiency are implemented.

Three papers address water management issues in the North Mongolian Kharaa River Basin. Priess et al. (2014) show that erosion could increase more than twofold in the steppe regions of the lower basin and up to sevenfold in the forested and mountainous upper basin due to the combined impacts of land use and climate changes. Promoted by government policies, there has been a recent intensification of agricultural activities as well as a spatial expansion of agricultural activities. Besides increasing competition over fertile land between animal herders and farmers cultivating cropland, agricultural production is currently expanding from riverine floodplains and valleys towards steeper sloping lands with higher erosion risks. The authors conclude that the combination of different land management practices which are adapted to the semiarid steppe environment, e.g., avoiding steep slopes, reductions in slope lengths (e.g., via strips of grassland or hedgerows) and mulching of croplands could in the future help to reduce land degradation and soil erosion. Karthe et al. (2014) describe the development of a science-based IWRM approach for the same river basin, where limited water availability, the combined effects of climate and land use changes and rising water consumption are likely to intensify quantitative and qualitative water scarcity. For the study region, the authors provide an integrative assessment of recent scientific findings on the state of regional water resources and aquatic ecosystems as well as sociopolitical developments. On this basis, they formulate recommendations for a science-based priority setting to come to an environmentally and socioeconomically sustainable water and land management. Rost et al. 2014 discuss the design of an IT-based decision support model for integrated urban water management and experiences with its application in a case study in the North Mongolian city of Darkhan. While generally aiming at water and nutrient recycling, and considering the entire river basin scale to address urban water management issues, the proposed model can flexibly be adapted to different (priority) settings.

Transboundary water resources and geopolitics

The Central Asian region is characterized by a large number of transboundary rivers (see Transboundary Freshwater Database, http://www.transboundarywaters.orst.edu). When rivers cross national borders, conflicts can occur over a particular state's right to use and divert waters which may happen at the expense or other riparian states. Countries located in the lower parts of river basins depend on water use policies and management strategies in adjacent upstream countries. In Central Asia, political conflicts about water availability, allocation and pollution have become more pronounced since the end of the Soviet Union as national interests of water, food and energy self-sufficiency have gained importance in the newly independent states (Unger-Shayesteh et al. 2013b). Political dialog and economic cooperation will in the future play an important role for agreements over transboundary water resources in the region.

Even though there are several international conventions as well as agreements between the Central Asian states on the use of transboundary water resources, there is a lack of legally binding agreements in the Central Asian region (Janusz-Pawletta 2014 Market-based mechanisms are considered to be one approach for the future management of transboundary water resources. This involves payments for water-related ecosystem services and compensations for profits lost due to water conservation by upstream users (Valentini et al. 2004; Khristovorov 2010). An important basis for a transboundary cooperation is a (harmonized) monitoring of water quantities (e.g., surface water runoff) and physico-chemical water quality.

In this thematic issue, Janusz-Pawletta (2014) provides an overview about current legal challenges to transboundary water resources management in the former Soviet republics of Central Asia. The author discusses joint management agreements (JMAs) at different spatial scales but points out that there is no internationally or regionally binding legal framework for transboundary cooperation. In this light, the International Fund for Saving the Aral Sea (IFAS), which itself has an unclearly defined legal status, is presented as the largest water-related cooperation platform in the Central Asian CIS states. Closely related to this paper is the discussion of water security issues by (Abdolvand et al. 2014), who consider the evolution of the food–water–energy nexus from pre- until post-Soviet times. The authors analyze the causes and consequences of water management problems, focussing on water, food and energy security and the role of transboundary cooperation and conflicts. Moreover, they highlight that capacity development at various levels is one of the most promising strategies to overcome today's obstacles for effective and sustainable water management at the local, national and Central Asian scale.

Jaguś et al. (2014) present a case study on transboundary cooperation in the Selenga–Baikal–Angara Basin, which shows that a water-related cooperation may in fact go beyond the water sector—in this case including hydropower transfers from Angara–Yenisei dams and gasoline exports from Russia to Mongolia.

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