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EDITORIAL

Water in Central Asia: an integrated assessment for science-based management

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Abstract Central Asia contains one of the largest internal drainage basins in the world, and its continental location results in limited availability of both surface and groundwater. Since the twentieth century, water resources of the region have been exploited beyond sustainable levels. From small Mongolian headwater streams to the mighty Aral Sea, surface waters have been partially desiccated. Demands from the agricultural, energy and raw material sectors as well as population growth have not only increased water abstractions, but also left a diverse and strong pollution footprint on rivers, lakes and groundwater bodies. Such changes in water quantity and quality have not only led to a degradation of aquatic and riparian ecosystems, but also they have placed the region's socioeconomic development at risk. Because of the complexity of Central Asia's water problems, integrated assessment and management approaches are required. Despite some shortcomings in practical implementation, the widespread adoption of the Integrated Water Resources Management and water–food–energy nexus approaches may be keys to a more sustainable future. This thematic issue aims to provide documentation of the current state of scientific knowledge, ranging from hydrological research to water quality investigations, and offers an assessment of ecosystems and the services provided by them. Reviews and case studies on different management options conclude the thematic issue by providing insights into field-tested solutions for the region's water challenges.

Keywords Central Asia · Water resources · Water quality · Water management

Introduction

About one-third of the world's drylands are located in Central Asia (Bai et al. 2012). In comparison with other regions, Central Asia has a large proportion of endorheic basins, which have internal drainage networks and therefore lack direct links to the ocean (Fig. 1). The levels,

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volumes and biogeochemical status of water bodies in endorheic basins are known to be sensitive to various changes in ambient conditions. This makes them vulnerable to climate change and other human pressures including agricultural intensification. Nevertheless, intelligent water management and sophisticated water distribution systems were allowed for the emergence of early civilizations in Central Asia (Dukhovny and Galina 2008; Varis and Kummu 2012). The idea of environmental protection was, for the first time in history, codified into law in Central Asia under the reign of Genghis Khan (from 1206 to 1227), including legislation which forbade water pollution (Farrington 2005).

Currently, over 80% of the Central Asian population lives under some form of water scarcity (Porkka et al. 2012). In particular, extreme physical water stress is widespread (Fig. 1), due to the fact that water withdrawal is approximately equal to water availability. A main contributing factor to this stress is that the countries of Central Asia have some of the world's highest per capita utilization of water (Varis 2014). For example, Turkmenistan's water use of 5000 m^3 per capita per year is about ten times the rate of Israel, which is also a major agricultural producer (Stone 2008). Such unsustainable water utilization in Central Asia has led to major environmental crises such as the desiccation of the Aral Sea (Glantz et al. 1993; Micklin 2010). The associated evapo-concentration of salt and contaminants has had severe consequences for the environment and local livelihoods (Törnqvist et al. 2011). In addition to pressures from high water utilization, the water systems of Central Asia are currently subjected to temperature increase that are considerably above the global average, comparable to the warming rate in more northern latitudes (Fig. 1).

Hence, the integrated assessment and sustainable management of Central Asia's water resources and aquatic ecosystems have received growing attention in recent years, not only by the international scientific community, but also from local, national and regional stakeholders in policy and administration. On the implementation side, a specific focus has been on holistic concepts such as Integrated Water Resources Management and the food–water–energy nexus (Guillaume et al. 2015; Ibisch et al. 2016a; Jalilov et al. 2015; Karthe et al. 2015b), which lie at the core of most national water management strategies of the region. Advances in water management increasingly require a sound scientific basis, which over the past decade was covered not only by several books and thematic issues in international journals, but also by the emergence of a specific journal focusing on water management in the Central Asian region (Table 1).

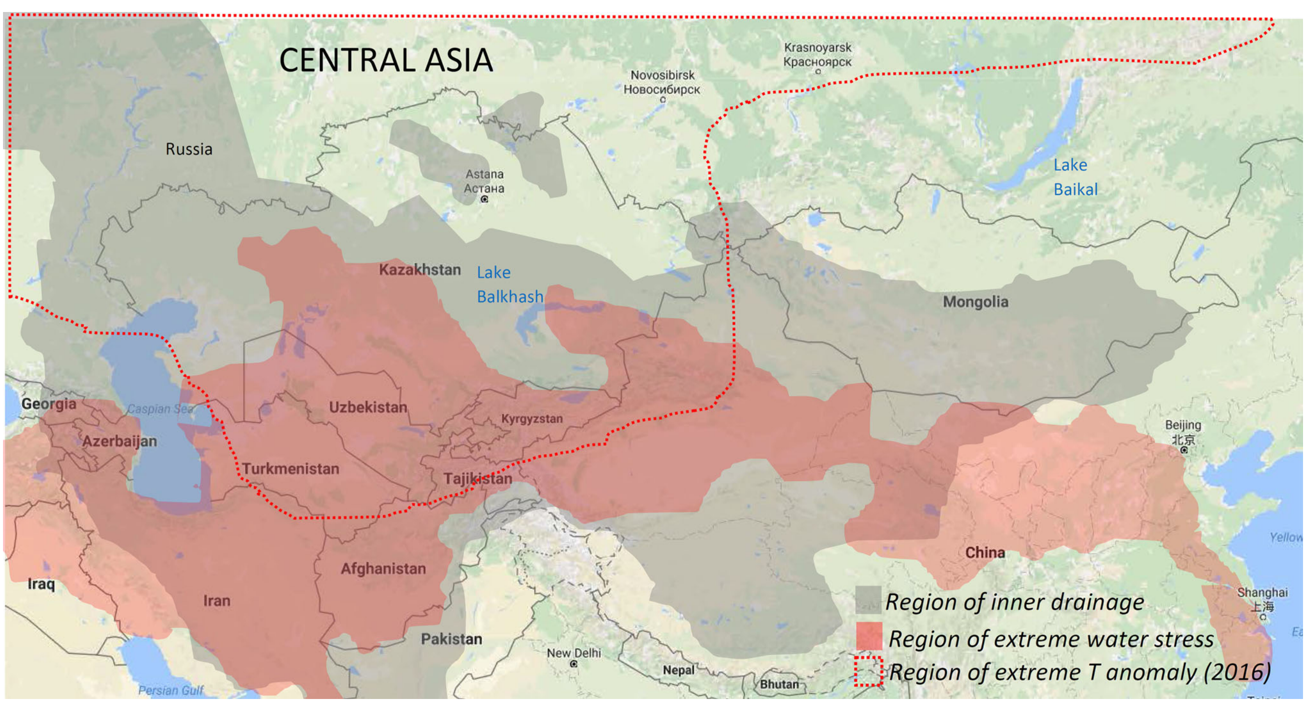

Fig. 1 Map of Central Asia, illustrating its extensive regions of inner drainage (gray shade), regions of extreme water stress where water withdrawal is approximately equal to water availability (red shade; Smakhtin et al. 2004; WWAP 2012), and regions of large temperature anomaly. Delineation by red-dotted line shows > 2.5 °C deviation from pre-industrial temperatures in an example from January to June 2016 (GISTEMP 2016)

Table 1 Recent literature on water resources and their management in Central Asia

Books	Chen J, Wan S, Henebry G, Qi J, Gutman G, Sun G, Kappas M (Eds) (2013): Dryland East Asia: Land Dynamics Amid Social and Climate Change. Berlin, Germany: de Gruyter and Beijing, China: Higher Education Press. 19 chapters, 470 pages
	Karthe D, Chalov S, Kasimov N, Kappas M (Eds) (2015): Water and Environment in the Selenga-Baikal Basin: International Research Cooperation for an Ecoregion of Global Relevance. Stuttgart, Germany: ibidem. 23 manuscripts plus editorial, 366 pages
	Madramootoo CA, Dukhovny VA (Eds) (2008): Water and Food Security in Central Asia. NATO Science for Peace and Security Series - C: Environmental Security. Dordrecht, The Netherlands: Springer. 19 manuscripts plus editorial, 212 pages
	Upcoming: Zhiltsov SS, Zonn IS, Kostianoy AG, Semenov AV (Eds) Water Resources in Central Asia. 3 volumes. Springer
Thematic Issues	Feng Z (Ed) (2013): Hydrological and ecological responses to climatic change and to land-use/land-cover changes in Central Asia. Quaternary International 311. 21 manuscripts plus editorial
	Feng Z (Ed) (2015): Climate changes and hydrological responses in the Tianshan Mountains and the northern Basins. Quaternary International 358. 30 manuscripts plus editorial
	Karthe D, Chalov S, Borchardt D (Eds) (2015): Water Resources and Their Management in Central Asia in the Early 21st Century: Status, Challenges and Future Prospects. Environmental Earth Sciences 73(2). 30 manuscripts plus editorial
	Stucki V, Wegerich K, Rahaman MM, Varis O (2012): Introduction: Water and Security in Central Asia—A Rubik's Cube. International Journal of Water Resources Development 28(3). 10 manuscripts plus editorial
	Unger-Sayesteh K, Vorogushyn S, Merz B, Frede HG (2013): Water in Central Asia—Perspectives under global change. Global and Planetary Change 110(A). 11 manuscripts plus editorial
	Upcoming: Berndtsson R, Tussupova K: The Future of Water Management in Central Asia. Water
Journal	Central Asian Journal of Water Research (CAJWR)
	http://www.water-ca.org/
	Established in 2016 and with articles published in Russian and English versions, CAJWR aims at bridging the gap between Central Asia and international scientific community. The multi-disciplinary e-journal covers the entire field of water research with a regional focus on Central Asia

This thematic issue consists of 30 manuscripts, which cover the following key aspects (more details are provided in the following thematic chapters):

- hydrology and water availability: monitoring and impacts of climate change;
- water quality and matter transport (e.g., sediments, contaminants);
- aquatic and riparian ecosystems; and
- water uses and management (e.g., irrigation and reservoir management, capacity development).

Key aspects addressed by the manuscripts in this volume are visualized in Fig. 2.

While not completely exhaustive, Fig. 2 indicates that "rivers" with their "runoff" and "drainage" functions in their regional settings ("region," "basin") play a prominent role in this thematic issue, which is not surprising given the magnitude of water withdrawals and pollution influxes from agriculture and mining industries in the riparian zones of many Central Asian rivers. "Lakes" are another important topic, which may be explained not only by the very large scale of some Central Asian Lakes, but also by a history of severe environmental degradation (e.g., the Aral Sea crisis) and their socioeconomic importance in this highly continental region. The frequent usage of the terms "data" and "management" is an indicative of the concurrent focus on system-related analyses and environmental assessments as fundamentals for science-based solution strategies. Not surprisingly, this often requires studies at the "basin" or "regional" scale. Furthermore, some key words point at hydrological and hydrochemical processes ("runoff," "streamflow," "sediment," "concentration," "pollutant"), processes at the basin scale ("land-cover," "irrigation") and challenges related to global change ("climate," "temperature," "precipitation"). Covering this wide range of aspects related to water, this thematic issue embeds 30 manuscripts on water in Central Asia in a more general scientific context. The editorial synthesizes the individual studies by organizing them in thematic groups in a way that the important interlinkages between water quantity, water quality, aquatic ecosystems and water use become apparent, and an integrated perspective of the region's water challenges and potential solutions can be taken.

Hydrology and water availability

Central Asia's climate is among the most continental in the world (Mannig et al. 2013). There are strong diurnal and intra-annual temperature amplitudes, ranging from winter minima below − 40 °C to summer maxima above + 40 °C

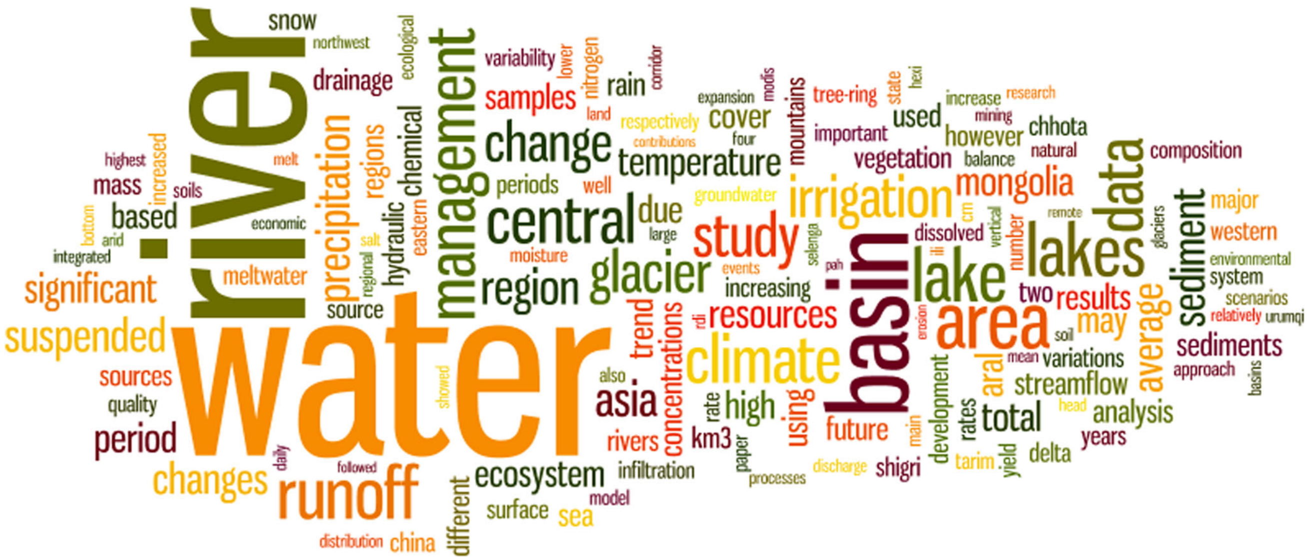

Fig. 2 Word cloud showing the most frequently used expressions in this thematic issue (based on manuscript titles and abstracts)

in many parts of the region (Malsy et al. 2012). At the same time, a limited precipitation (typically between 100 and 400 mm per year) coincides with high rates of potential evaporation (more than 900–1500 mm per year) (Bai et al. 2012; Karthe et al. 2014). For example, the Taklamakhan and Gobi deserts are among the regions with the lowest natural water availability in the world (Mekonnen and Hoekstra 2016) and make up about a quarter of Central Asia's land area (Bai et al. 2012).

High mountain zones play a vital role for the water supply in Central Asia's vast lowlands by acting as "water towers" with a high relevance for runoff and groundwater generation (Farinotti et al. 2015; Kopp et al. 2014; Lutz 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). One of the most prominent examples is the Tarim River, which is almost entirely fed by precipitation in its mountainous headwater zone, which sharply contrasts with the hyperarid deserts farther downstream (Keilholz et al. 2015). High mountain zones are not only important source areas for Central Asia's streams, but glaciers and snow pack also provide an intermediate storage of water resources. While glaciers also store water over long periods, thereby balancing seasonal and interannual water availability, both glaciers and the seasonal snow pack release water during the summer season when it is most needed for agricultural production (Hagg et al. 2007; Unger-Sayesteh et al. 2013). The projected further melting of Central Asian glaciers in the future is therefore expected to contribute to reduced summer runoff in the long run (Pritchard 2017), an effect that probably will be aggravated by hydropower expansion and associated storage of summer discharge to meet energy needs during the winter season. Even though the mean fraction of runoff generated from ice melt is only 8–9% in Central Asia, it is concentrated in only a few months and can strongly increase summer runoff (Hagg et al. 2007). In the high mountain river basins of the Northern Tien Shan, for example, glacier melt contributes 18–28% to annual runoff and up to 70% to summer runoff (Aizen et al. 1996; Dikich and Hagg 2003). Moreover, there is observational evidence that large-scale permafrost thaw in mountain regions of Central Asia has decreased the annual maximum flows and increased the annual minimum flows (Törnqvist et al. 2014), due to a dampening effect of increased groundwater storage in areas of reduced permafrost. In particular, decreased maximum flows may have large impacts beyond the mountain regions, due to the importance for basin-wide sediment and pollutant transport (Jarsjö et al. 2017; Pietroń et al. 2015; Thorslund et al. 2016).

Central Asia's lowlands are home to several major river systems and lake basins (Karthe 2017). Many of them are fed by runoff from high mountain areas, and many of them are endorheic, including the Amu Darya–Syr Darya–Aral Sea Basin and the Ili River–Lake Balkhash Basin (Varis and Kummu 2012). In Central Asia's lowlands, natural ecosystems have evolved according to natural water availability. However, population and water-consuming economic activities have increased to a degree that water use has shifted away from natural processes, thereby significantly altering the way socioecological systems work (Gordon et al. 2008; Renaud et al. 2013), with a "high probability of (possibly abrupt) water-induced changes with large detrimental impacts on human societies" (Gerten et al. 2013). In several arid lowland areas of Central

Asia, inland lakes are the most important water resources. Because many of the lakes are large but relatively shallow (Karthe 2017), they are important indicators of climate changes and anthropogenic impacts (Bai et al. 2012). In the Middle Asian states (i.e., the formerly Soviet "-stans") alone, there are about 6000 lakes (Savvaitova and Petr 1992). Wherever lakes are fed by major rivers, deltas exist that are not only relevant as biogeochemical filters of the lakes, but also as wetlands of supraregional importance (Chalov et al. 2016; Karthe 2017; Starodubtsev and Truskavetskiy 2011).

Central Asia is considered as a "hot spot" of climate change, a fact that is expected to have serious consequences for the region's water resources (Unger-Sayesteh et al. 2013; also see Fig. 1). 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 (Mannig et al. 2013). According to Yu et al. (2003), "the center of the warming zone appears to lie just southeast of Lake Baikal, putting the drylands of northern China and Mongolia near the center of this hot spot." However, global climate models are known to perform poorly in the region and tend to overestimate precipitation (Malsy et al. 2013; Mannig et al. 2013; Bring et al. 2015). Therefore, there is a considerable uncertainty about both the direction and magnitude of future precipitation change, with current global circulation models unable to reproduce recently observed changes (Bhend and Whetton 2013; Törnqvist et al. 2014). For several Central Asian rivers, it is nevertheless predicted that the combined effects of water withdrawals and climate change are likely to lead to a reduced streamflow in the future (Karthe et al. 2017; Malsy et al. 2016; Stone 2008; Varis 2014).

In this thematic issue (Table 2), 11 manuscripts deal with the regional hydrology and issues of water availability. The manuscript by Micklin deals with the desiccation of the Aral Sea and subsequent efforts to restore the lake's hydrology and ecology. The author discusses the lessons learned from what is one of the greatest but manmade environmental disasters in the world. Moreover, he analyzes the scopes and limits of restoration efforts in a political, ecological and economic perspective. Conrad et al. investigated small lakes in the inner Aral Sea Basin and found their volumes to increase during the irrigation period. The authors interpreted this as an indicator for inefficient irrigation and excess water inflow into these lakes and concluded that an Integrated Water Resources Management in the region should also consider these small lakes as a potential water source.

Two manuscripts have their focus on precipitation. Vandandorj et al. assessed the typology of summer rains in Mongolia between 1981 and 2014. For only a small number of meteorological stations, the authors detected a precipitation decline, whereas for most stations, the total summer precipitation did not change much during this period. However, there was a significant trend toward relatively heavy convectional rainfall, whereas the number of more moderate stratiform rain events decreased. The authors concluded that there might be feedback loops between increasing temperature and altered rain types since decreasing durations and numbers of stratiform rain events are allowed for progressively longer sunshine periods. Operational monitoring of snowfall, which is a very relevant form of precipitation in Central Asia in general and the region's high mountain areas in particular, is discussed by Gafurov et al. The authors developed a tool called MODSNOW which processes raw satellite data (of the MODIS instruments) and uses cloud removal algorithms to produce daily snow-cover maps with only a minimum delay (about 2 days). Applications of such tool include not only operational use for water management, but also the analysis of historical time series for scientific investigations.

Another five manuscripts deal with moisture and streamflow assessments in different river basins and time periods. The study by Chen and Yuan reconstructed the historical streamflow of the Guxing River and drought variation in the Eastern Tien Shan by tree-ring analysis for the period between 1680 and 2009. The authors did not only note a significant decrease in runoff since the 1970s, but also a strong similarity of the pattern with West-Central Mongolia and the Selenga River. Deng et al. conducted a meta-study based on existing reconstructions of moisture for the Qilian Mountains in northwestern China. For a period of almost nine centuries, the authors could identify comparable temporal pattern for different parts of the Qilian Mountains which also agreed well with findings from other nearby regions. Sun et al. compared streamflow components of the Urumqi River (northern slope of the Tien Shan Mountains) and the Huangshuigou River (southern slope of the Tien Shan). While they identified groundwater as the main source feeding both rivers, they found the Urumqi River to be more sensitive to temperature changes, with strong positive temperature anomalies enhancing glacier melt and consequently floods. The manuscript by Xu et al. addresses the modeling of future runoff based on downscaled climate predictions and the hydrological model SWAT. For the Kaidu River Basin on the southern slope of the Chinese Tien Shan, the authors found a significant rise in temperature, but rather indistinctive change in precipitation. According to their model results, runoff in the Kaidu River is likely to remain stable under a moderate emission scenario (B2), while high emissions (A2 scenario) would result in reduced runoff in the near future (soon after 2020). For the Tarim River, Li et al. investigated the characteristics of soil infiltration in the

Table 2 Manuscripts in the *Hydrology and Water Availability* section

Chen F, Yuan Y: Streamflow reconstruction (1680–2009) for the Guxiang River, eastern Tien Shan (China): linkages to the surrounding rivers of Central Asia. doi:10.1007/s12665-016-5849-1
Conrad C, Kaiser BO, Lamers JPA: Quantifying water volumes of small lakes in the inner Aral Sea Basin, Central Asia, and their potential for reaching water and food security. doi:10.1007/s12665-016-5753-8
Deng Y, Gou X, Gao L, Yang M, Zhang F: Tree-ring recorded moisture variations over the past millennium in the Hexi Corridor, northwest China. doi:10.1007/s12665-017-6581-1
Gafurov S, Luedtke S, Unger-Shayesteh K, Vorogushyn S, Schöne T, Schmidt S, Kalashnikova O, Merz B: MODSNOW-Tool - an operational tool for daily snow cover monitoring using MODIS data. doi:10.1007/s12665-016-5869-x
Li X, Feng G, Zhao C, Shi F: Characteristics of Soil Infiltration in the Tarim River Floodplain. doi:10.1007/s12665-016-5573-x
Mandal A, Ramanathan A, Angchuk T, Soheb M, Singh VB: Unsteady state of glaciers (Chhota Shigri and Hamtah) and climate in Lahaul and Spiti region, western Himalayas: a review of recent mass loss. doi:10.1007/s12665-016-6023-5
Micklin P: The Future Aral Sea: Hope or Despair? doi:10.1007/s12665-016-5614-5
Sun C, Yang J, Chen Y, Li X, Yang Y, Zhang Y: Comparative study of streamflow components in two inland rivers in the Tianshan Mountains, Northwest China. doi:10.1007/s12665-016-5314-1
Vandandorj S, Munkhjargal E, Boldgiv B, Gantsetseg B: Changes in event number and duration of rain types over Mongolia from 1981 to 2014. doi:10.1007/s12665-016-6380-0
Wang X, Liu Q, Liu S, Wei J, Jiang Z: Heterogeneity of glacial lake expansion and its contrasting signals with climate change in Tarim Basin, Central Asia. doi:10.1007/s12665-016-5498-4
Xu C, Zhao J, Deng H, Fang G, Tan J, He D, Chen Y, Chen Y, Fu A: Scenario-based runoff prediction in the Kaidu River basin of the Tianshan Mountains, China. doi:10.1007/s12665-016-5930-9

river's floodplains. The authors did not find any correlation between soil organic content and infiltration, but identified strong links not only between soil texture and infiltration but also the presence or absence of surface crusts, which significantly reduced infiltration rates (by a factor of about six).

Finally, two manuscripts deal with glacial processes in headwater regions. Wang et al. analyzed the pattern of glacial lake expansion in the Tarim River Basin between 1990 and 2013. Despite spatial heterogeneity (stronger expansion in the Altun Shan and Tien Shan, weaker expansion in the Pamir and Karakorum), the authors detected a recent acceleration in glacial lake expansion which they interpret as a consequence of climate change-induced glacier melt. A meta-study on two reference glaciers in the Western Himalayas (Chhota Shigri and Hamtah glaciers) by Mandal et al. found significant mass losses and surface thinning. A recent acceleration was observed for both processes, largely driven by rising temperatures and some decrease in precipitation. The authors noted that summer snowfall on the glacier, which occurs only in some years, is of particular relevance for the glacier mass balance because of the resulting albedo increase (which may reduce glacier melt to a degree that allows for a positive mass balance in such years).

Water quality and aquatic/riparian ecology

Regions that are not 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 2012). In Central Asia, where surface 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. 2015). Alterations of the hydrology often reinforce such changes in hydrogeochemistry. Precipitation patterns have changed, and these changes, in combination with drying trends of water bodies due to increasing temperatures and have resulted in loss of water bodies, including drying lakes and retreating glaciers (Unger-Sayesteh et al. 2013; Kang et al. 2015). Moreover, climate change and land reclamation for agriculture and—in some regions—mining are important drivers of the degradation of both forests and riparian zones (Batbayar et al. 2017; Kopp et al. 2016; Lange et al. 2015).

Water pollution in Central Asia has three principal causes. Agriculture is not only a major water user, but also a major water polluter in the region. Groundwater and surface water in the Aral Sea Basin, for example, have been heavily polluted due to fertilizer and pesticide residues, and desiccation of water bodies may lead to eolian transports of such pollutants over long distances (Glantz 1999; Groll et al. 2015; Opp et al. 2016). Moreover, agricultural activities are a frequent source of soil and water salinization (Crosa et al. 2006; Kuba et al. 2013; Olsson et al. 2013; Thevs et al. 2013) and facilitate erosion and the influx of fine sediments, nutrients and agrochemicals into surface water bodies (Chalov et al. 2013; Groll et al. 2015; Pietroń et al. 2017; Theuring et al. 2015) where they may adversely affect the aquatic ecosystem (Hartwig and Borchardt 2014). In contrast to other parts of Central Asia, rapidly rising water consumption from the agricultural sector is evident in Mongolia. In December 2016, Mongolia had 61.5 million heads of livestock, the highest ever number of free-ranging animals (NSO 2016). Because they stay close to water bodies, consequences include organic pollution (Puntsag et al. 2010) and the degradation of riparian vegetation with subsequent destabilization of river banks, which become sensitive to erosion and may be the most significant source of sediment loads to rivers (Hartwig and Borchardt 2014; Theuring et al. 2015).

While some parts of Central Asia have experienced a recent depopulation, the region's overall population continues to grow. Improper municipal wastewater management in growing urban areas is another major pressure, leading to rising pollution levels in rivers and groundwater with regard to organic substances, nutrients and pathogens (Batbayar et al. 2017; Darracq and Destouni 2005; Hofmann et al. 2011; Karthe et al. 2016; Malsy et al. 2016), and posing sanitary risks for local settlers (Bosch et al. 2007; Karthe et al. 2016; Sorokovikova et al. 2013; Uddin et al. 2014). While in recent years, programs for the renewal of urban wastewater infrastructures have started in many parts of the region, decentral options still tend to be neglected, but would be viable solutions in regions with small settlements and low population densities (Khurelbaatar et al. 2017). A problem that has been investigated only very recently in Central Asia is that of freshwater microplastics pollution. Free et al. (2014) found that one of the most remote lakes in the world, Mongolia's Lake Hövsgöl, was more heavily polluted with microplastics, including residues of plastic bottles, fishing gear and plastic bags than large parts of the Laurentian Great Lakes. Later studies have found that the problem is widespread in the region (e.g., Zhang et al. 2016).

The highly diverse raw material sector in Central Asia, with a widespread exploitation of oil, gas, coal, various metallic resources and rare earth elements, is another major water user and polluter. On the shores of the Caspian Sea, rising sea levels since the late 1970s and a recent stabilization at 2 m above the historical level have affected and sometimes completely submerged oil and gas fields located on the seashore, polluting coastal zones and the marine ecosystems (Dahl and Kuralbayeva 2001). A region that well exemplifies the environmental risks of mining is the Selenga River—Lake Baikal Basin, where coal, gold, copper, wolfram and molybdenum are extracted from relatively shallow deposits (Chalov et al. 2015; Kasimov et al. 2017; Sandmann 2012; Thorslund et al. 2012, 2016). Over the past 15 years, the Mongolian government has been particularly active in encouraging foreign mining companies to start business in Mongolia (Farrington 2005). As a consequence of mining, elevated levels of heavy metals and other mining-related pollutants have been detected in the water and sediments of the Selenga River and its tributaries, as well as floodplain soils and groundwater (Batbayar et al. 2017; Brumbaugh et al. 2013; Chalov et al. 2015; Inam et al. 2011; Karthe et al. 2017; Nadmitov et al. 2014; Pavlov et al. 2008; Thorslund et al. 2012). Moreover, bioaccumulation and toxicological effects observed in aquatic biota ranging from insects to fish have been documented (Avlyush 2011; Kaus et al. 2016b; Komov et al. 2014). Different sources of evidence suggest that small-scale gold mining is particularly problematic and some regions suffer from legacy contamination with heavy metals (Kaus et al. 2016b). Challenges include a lack of environmental monitoring and management, the relatively quick transience of small mines and their spatially diffuse development (McIntyre et al. 2016; Pfeiffer et al. 2015). Even though contaminant transport toward the Selenga delta does take place (Chalov et al. 2015; Malsy et al. 2016; Thorslund et al. 2012), it should be noted that contaminations currently have the largest effects in local hot spots (Hofmann et al. 2015; Inam et al. 2011; Kaus et al. 2016b; Pfeiffer et al. 2015). Currently, there are different views regarding their impact on Lake Baikal itself. Because of its large volume (more than 23,000 km^3), some experts argue that Lake Baikal will be slow to show changes from anthropogenic pollution (Callender and Granina 1997). However, there are concerns that the Selenga River Delta, which constitutes the final geobiochemical barrier before the river discharges into Lake Baikal, may lose some of filtration capacity as a consequence of changing hydrological conditions and contaminant loads from regions further upstream (Chalov et al. 2016).

Aquatic ecosystems of Central Asia are characterized not only by regionally diverse climates, hydrology and hydro-geological conditions, but also by strong links between ecosystem services and people's lifestyles (including highly adapted traditions such as nomadism or oasis cultures). On the one hand, the region's semi-arid to arid climate typically leads to substantial seasonal differences in flow and riparian zone inundation. Strong temperature contrasts and harsh winters are another climatic feature which leads to highly adapted ecosystems which at the same time are vulnerable to external changes (Avlyush et al. 2013; Hülsmann et al. 2015; Karthe 2017). Mongolia and neighboring regions in Russia and China are home to some of the longest undammed river systems in the world, with its fully connected river systems being an important prerequisite for the survival of red-listed fish species such as the Siberian taimen (*Hucho taimen*) (Kaus et al. 2016a). However, potential plans for the construction of dams and increasing recreational fishing put these populations under rising pressure (Kasimov et al. 2017; Kaus et al. 2016a). In other parts of Central Asia, natural aquatic ecosystems have already been transformed by human activities to a degree that completely changed their ecology (Dukhovny and Galina 2008).

In this thematic issue (Table 3), research on river processes ranges from glacier meltwaters (Singh et al.) to the rivers of the Eastern Siberian plains (Semenov et al.). Four manuscripts (Hartwig et al., Kasimov et al., Myangan et al. and Lychagin et al.) address the Selenga River and its tributaries, with a specific focus on the impacts of mining, agriculture and urban areas. Studies on water quality focus in particular on the Khangai Mountain Region (Baatar et al.) and the Aral Sea (Micklin). A study on wetland ecosystems is presented by Thevs et al. who analyzed recent changes in the Ili River Delta, Kazakhstan, whereas Keyimu et al. calculated the seasonal pattern of water consumption by riparian forests along the lower Tarim River in China.

Two papers deal with a glacier region at the southern fringe of Central Asia. Singh and Ramanathan studied the chemical compositions of meltwater of the Chhota Shigri glacier in the Western Himalayas. Their findings pinpointed at carbonate-type weathering as the dominant source of solutes. Concentrations of total dissolved solutes and major ions showed inverse relationship with meltwater runoff (the peak flow period had minimal solute concentrations), while there was an indication that cation weathering rate by meltwater was elevated during the peak melt season due to high runoff. A related team of authors, Singh et al., also examined glacial runoff and suspended sediment transport for the same river. The period from June to August was characterized by the highest discharge, with daily maxima in the evening and minima in the morning. Daily mean concentrations of suspended sediment as well as the suspended sediment loads were highest in the same period due to its strong association with meltwater runoff.

The manuscripts by Kasimov et al. and Myangan et al. provide an overview about water, sediment and soil pollution in the transboundary Selenga River Basin, with a specific focus on land-use changes and the environmental footprints of Ulaanbaatar and Ulan-Ude cities as well as Erdenet and Zakamensk mining centers. Based on field studies carried out between 2011 and 2015, Kasimov et al. conclude that the soils of Ulaanbaatar and Ulan-Ude cities typically exhibit low levels of pollution by different elements. They found a different situation in the mining centers: In Erdenet, there is a substantial environmental enrichment with ore elements (Cu, Mo) and As; in Zakamensk, non-ore elements (Pb, Sb, Cd, As) were detected at hazardous levels. The authors identified a more seasonal pattern of instream pollution in the Tuul downstream of Ulaanbaatar as compared to the Selenga River near Ulan-Ude. Despite a significant increase in the ore element concentrations in the bottom sediments of second- or third-order tributaries of Selenga River, bottom sediments in the Selenga's main channel were found to be less polluted due to sediment and associated contaminant deposition. The findings of this manuscript are corroborated and complemented by Myangan et al. who report on the impact of different land uses on heavy metal distribution in Selenga River system within Mongolia. The authors conducted monthly samplings of suspended solids at six gauging stations along the Selenga between 2009 and 2013 plus a more comprehensive sampling campaign in 2013. Cr, Cu

Table 3 Manuscripts in the *Water Quality and Aquatic/Riparian Ecology* section

Baatar B, Chuluun B, Tang SL, Bayanjargal O, Oyuntsetseg B: Vertical distribution of physical–chemical features of water and bottom sediments in four saline lakes of the Khangai mountain region, Western Mongolia. doi:10.1007/s12665-017-6447-6
Hartwig M, Schaeffer M, Theuring P, Avlyush S, Rode M, Borchardt D: Cause-effect-response chains linking source identification of eroded sediments, loss of aquatic ecosystem integrity and management options in a steppe river catchment (Kharaa, Mongolia). doi:10.1007/s12665-015-5092-1
Kasimov NS, Kosheleva NE, Gunin PD, Korlyakov I, Sorokina OI, Timofeev IE: State of the Environment of Urban and Mining Areas in the Selenga River Basin. doi:10.1007/s12665-016-6088-1
Keyimu M, Halik Ü, Kurban A: Estimation of water consumption of riparian forest in the lower reaches of Tarim River, northwest China. doi:10.1007/s12665-017-6801-8
Lychagin MY, Chalov SR, Kasimov NS, Shinkareva GL, Jarsjö J, Thorslund J: Surface water pathways and fluxes of metals under changing environmental conditions and human interventions in the Selenga River system. doi:10.1007/s12665-016-6304-z
Myangan O, Kawahigashi M, Oyuntsetseg B, Fujitake N: Impact of land uses on heavy metal distribution in the Selenga River system in Mongolia. doi:10.1007/s12665-017-6664-z
Semenov MY, Marinaite I, Bashenkaeva N, Zhuchenko N, Khuriganova O, Molozhnikova E: Polycyclic Aromatic Hydrocarbons in a Small River in Eastern Siberia, Russia: Sources, Delivery Pathways and Transformation. doi:10.1007/s12665-017-6465-4
Singh VB, Ramanathan A, Pottakal JG: Glacial runoff and transport of suspended sediment from the Chhota Shigri glacier, Western Himalaya, India. doi:10.1007/s12665-016-5271-8
Singh VB, Ramanathan A: Hydrogeochemistry of the Chhota Shigri glacier meltwater, Chandra basin, Himachal Pradesh, India: solute acquisition processes, dissolved load and chemical weathering rates. doi:10.1007/s12665-017-6465-4
Thevs N, Beckmann V, Khalil A, Köbbing JF, Nurtazin S, Hirschelmann S, Piechottka T, Salmyrzauli R, Baibagysov A: Assessment of ecosystem services of the wetlands in the Ili River Delta, Kazakhstan. doi:10.1007/s12665-016-6346-2

and Zn were found in high concentrations downstream of urban and mining areas and transported by suspended solids. Along some tributaries, the authors identified agriculture as the main driver of soil erosion, leading to large mass flows of soil particles in tributary streams (Sharyn and Kharaa Rivers). Lychagin et al., on the other hand, evaluated pathways and mass flows of heavy metals and metalloids in both dissolved and suspended forms, based on hundreds of samples collected between 2011 and 2013. Urban (Ulaanbaatar and Ulan-Ude) and industrial centers (Zaamar gold mining and Zakamensk wolfram–molybdenum mining) had a strong effect on water quality degradation over short distances (3–6 times increase in heavy metal and metalloid concentrations). The study also found the Selenga River to have enriched levels of both dissolved and suspended levels of metals as compared to world averages in surface waters. The authors warned that increased suspended loads during the summer flood reached levels that could lead to substantial bioaccumulation and biomagnification in the aquatic food chain and even human health risks. Hartwig et al. examined the system-level cause–effect-response chains related to river bank erosion, resulting fine sediment transport and deposition and ultimately their effects on the ecological status. Based on a case study for the Kharaa River in northern Mongolia, the authors conclude that important management measures in the region should include the stabilization of river banks, particularly by restricting livestock access.

One and three manuscripts, respectively, deal with water quality issues in rivers and lakes. Semenov et al. investigated sources of polycyclic aromatic hydrocarbons, which are mutagens and carcinogens, in Olka River, a small tributary to Irkutsk River in Eastern Siberia in 2014–2015. They found that the riverine water was mainly polluted by oil-fired boilers, whereas the bottom sediments were equally polluted by wood combustion, oil-fired boilers and aluminum smelters, although the delivery pathways were governed by climatic conditions. The differences in the PAH source contributions among sites were due to both different proportions of the flow components and different positions of the sites relative to the emission sources. Baatar et al. studied the West Mongolian Lakes Telmen, Oigon, Tsegeen and Khag with regard to trace elements and major ionic components and their association with the vertical profiles of water and sediment. The authors found the chemical compositions of Lakes Khag and Tsegeen similar to each other, but significantly different from those of Lakes Telmen and Oigon. Moreover, they conclude from their findings that Lake Oigon is the most strongly stratified lake in Mongolia according to present knowledge.

Wetland ecology is at the focus of a manuscript by Thevs et al. who evaluated ecosystem services of the Ili River Delta in Kazakhstan, which constitutes one of the largest natural deltas and wetland complexes in Central Asia. Using a remote sensing approach, the authors estimated wetland and reed (*Phragmites*)-dominated areas, which was then used to estimate reed bed biomass. Reed beds were identified not only as a significant natural resource for fish spawning and livestock grazing, but also as a raw material for chipboard and paper production and ecotourism. Riparian zone ecology is the topic of a last manuscript. Keyimu et al. investigated the water consumption of *Populus euphratica* forests along the lower Tarim River. The authors found a positive correlation of sap flow with temperature and a negative correlation with humidity and recommended that local authorities should incorporate the findings to determine the optimum allocation of water for natural ecosystems versus irrigated agriculture.

Water usage and management

The water sector in Central Asia has undergone two radical transformations that were related to the establishment and subsequent collapse of the Soviet Union. Even in regions that were not part of the Soviet Union such as Mongolia and the western parts of China, similar developments took place due to the rise of communism in the early twentieth century and substantial socioeconomic transformations which began in the late twentieth century and are typically still ongoing (Abdullaev and Rakhmatullaev 2015; Groll et al. 2015; Heldt et al. 2017).

The socialist legacy of water management controlled by central governments continues to influence the region's water sector. A very strong degree of integration of the water and energy sectors existed in the Middle Asian republics, where water allocation arrangements were mainly based on two complimentary considerations: The central government in Moscow (1) allocated and strictly controlled water provisions to the Middle Asian republics and (2) planned the delivery of energy to the Kyrgyz and Tajik Soviet Republics during the winter (Libert et al. 2008). While water management in the Soviet era was seen as efficient due to clearly regulated interactions between water authorities and water user throughout the region, a strong centralization of the water-apportioning process often failed to take into account recommendations and demands of local administrations. At the same time, the region's unified hydraulic infrastructure raised transboundary reservoir management issues over water resources allocation among the countries in the region (Propastin 2012; Rakhmatullaev et al. 2013; Sakal 2015).

Recent water sector reforms in Central Asia have been driven both by endogenous developments and external influences such as the "import" of experiences from elsewhere. On the one hand, water use and management in Central Asian countries are still strongly influenced by the region's history and traditions (Abdullaev and Rakhmatullaev 2015; Karthe et al. 2015a). On the other hand, most of the Central Asian countries have implemented the concept of Integrated Water Resources Management (IWRM) at least to some degree (Abdullaev and Rakhmatullaev 2015; Heldt et al. 2017; Karthe et al. 2015a). Even though external actors have promoted the implementation of IWRM/RBM (for example by capacity development), in many Central Asian countries national actors are the key drivers for reforms (Dombrowsky et al. 2014). The high relevance of external donors for IWRM implementation in Central Asia is nevertheless problematic, raising the need of greater local ownership of water management planning (Borchardt et al. 2013). Even though some concepts such as irrigation management transfer (IMT), joint management (JM) or participatory irrigation management (PIM) have been a core of international support for water sector reforms in Central Asia, their successes have so far been limited and water infrastructures in almost in all countries are de facto still in the hands of the state. The nexus concept, which considers the tradeoffs between different water-dependent activities, has recently received a strong attention for mitigating Central Asia's water challenges. Typically, a strong emphasis is on energy and food, because (a) hydropower plays a significant role for regional energy production and (b) irrigation is the largest single consumer of water (de Strasser et al. 2016; Guillaume et al. 2015). In fact, a centrally managed water–food–energy nexus existed during socialist times, but collapsed with the breakup of the Soviet Union (Bekchanov and Lamers 2016). Today, key challenges for the implementation of the IWRM and nexus concepts include (a) outdated infrastructures in the water, irrigation/food production and energy sectors, (b) transboundary disputes, (c) data scarcity, (d) capacity deficits in various parts of the water sector and (e) inefficient governance structures. While the complexity of water problems is already challenging in the world's most developed countries, in Central Asia the latter three aspects are additional obstacles for water management planners (Dombrowsky et al. 2014; Ibisch et al. 2016b; Karthe et al. 2015b; Kirschke et al. 2017).

In this thematic issue (Table 4), three manuscripts focus on institutional and legal aspects of water management. Abdullaev and Rakhmatullaev analyzed the implementation of the river basin approach in the Isfara Basin (Ferghana Valley, Uzbekistan). The authors provide a current account of the issues, challenges and recommendations for implementation of the river basin concept for the region. In an opinion paper, the same authors (Abdullaev and Rakhmatullaev) outline their vision for how existing institutional platforms, such as basin councils, can help to implement a nexus approach in local river catchments, regional watersheds or at the national level. Boklan and Janusz-Pawletta discuss the issue of interstate cooperation in the water sector in the context of the Eurasian economic integration. For the Central Asian states, they conclude that transboundary cooperation in the water sector requires further enhancements regarding both an interstate regulatory framework (considering ecological aspects and economic developments) and institutional capacities in the region. Capacity development as a prerequisite for the successful implementation of Integrated Water Resources Management (IWRM) is addressed by Karthe et al. who analyzed the role of a school network setup within the context of a research and development project on water resources management in northern Mongolia.

All remaining papers consider the dependencies between water management and food production, thereby giving insights into the multiple interdependencies between both sectors. One important prerequisite for sustainable agriculture is the assessment of water resources availability. The regional geography determines suitable extents of agriculture. Guo et al. assessed potential scales of irrigation in oases at the example of the Hotan River Basin in Western China. Their analysis is based on the distribution characteristics of natural vegetation in the river basin via remote sensing images, data on water resources, climate, socioeconomic information and field surveys. Li et al. analyzed recent (1961–2013) temperature and precipitation trends in the Tienshian Mountain Region (TMR) and its effects on wheat production. The authors observed (1) a trend toward extreme climatic events; (2) the highest warming rates in the eastern TMR, and the largest wetting trend on the northern slopes of TMR; and (3) significant correlations between wheat yield and the occurrence of extreme temperature or precipitation. Besides sufficient water availability, water quality is another important aspect in the water–food nexus. In drylands such as those of Central Asia, irrigation systems often involve subsequent drainage outflows, which due to nutrients and pesticides may negatively affect groundwater or surface water quality. According to the findings of Jarsjö et al., future climate change impacts will reduce runoff and lead to increase of internal nitrogen recirculation ratios in Central Asian rivers, thereby reducing instream concentrations. However, in groundwater near agricultural fields, there is a risk of considerable nitrogen accumulation. Land degradation due to salinization is another problem of water and land management in Central Asia that is linked to the region's arid climate. Hu et al. conducted an analysis of the salt balance of the Weigan River irrigation district in Western China based on measured data. According to the authors, from 1994 onwards, the irrigation district turned from salt

Table 4 Manuscripts in the *Water Usage and Management* section

Abdullaev I, Rakhmatullaev S (2016a): River Basin Management in Central Asia: Evidence from Isfara Basin, Fergana Valley. Environmental Earth Sciences 75:677. doi:10.1007/s12665-016-5270-9
Abdullaev I, Rakhmatullaev S (2016b): Setting Up the Agenda for Water Reforms in Central Asia: Does the Nexus Approach Help?
Groll M, Kulmatov R, Mullabaev N, Belikov A, Opp Ch, Kulmatova D: Rise and decline of the fishery industry in the Aydarkul-Arnasay lake system (Uzbekistan)—effects of reservoir management, irrigation farming and climate change on an unstable ecosystem. doi:10.1007/s12665-016-5691-5
Guo H, Ling H, Xu H, Guo B: Study of suitable oasis scales based on water resource availability in an arid region of China: a case study of Hotan River Basin. doi:10.1007/s12665-016-5772-5
Hu S, Zhao C, Zhu H: Hydrosalinity balance and critical ratio of drainage to irrigation (RDI) for salt balance in Weigan River irrigation district located in the Tarim basin. doi:10.1007/s12665-017-6543-7
Janusz-Pawletta B, Boklan D: Watercourses in Central Asia under the conditions of Eurasian economic integration. doi:10.1007/s12665-017-6741-3
Jarsjö J, Törnqvist R, Su Y: Climate-driven change of nitrogen retention—attenuation near irrigated fields: Multi-model projections for Central Asia. doi:10.1007/s12665-017-6418-y
Karthe D, Reeh T, Niemann S, Siegmund A, Walther M (2016): School-based environmental education in the context of a research and development project on integrated water resources management: experiences from Mongolia. doi:10.1007/s12665-016-6036-0
Li C, Wang R, Ning H, Luo Q: Changes in climate extremes and their impact on wheat yield in Tianshan Mountains region, northwest China. doi:10.1007/s12665-016-6030-6

accumulation to desalinization and the ratio of drainage to irrigation tended to an optimal value. A last paper in this chapter addresses the fishery sector. Groll et al. analyzed the effects of regional anthropogenic and global climate change impacts on the Aydarkul–Arnasay Lake System (AALS) in Central Asia. Originally, a shallow saline depression between the Kyzylkum and the Nurata Mountain Range, the AALS was created in 1969 due to catastrophic floods in the Syr Darya River related to an overflow of the Chardarya reservoir. It subsequently became an important center of fishery. More recently, a negative water balance and the inflow of polluted water have threatened this ecologically and economically important lake system.

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