Quaternary International xxx (2017) 1–10

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

# Environmental changes in Central and East Asian drylands and their effects on large Central and East Asian lakes and their effects on major river-lake systems

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ARTICLE INFO

*Article history:*
Received 30 June 2016
Received in revised form
21 November 2016
Accepted 28 January 2017
Available online xxx

*Keywords:*
Central Asia
Lakes
Rivers
Lake Baikal
Selenga
Aral Sea
Amu Darya
Syr Darya
Tarim

ABSTRACT

Even though the drylands of Central and Eastern Asia are among the most continental regions of the world, they are also home to some of the largest rivers and lakes in the world. Because of a low population density, many of these water bodies have remained in relatively pristine condition until the mid-20th century, when urbanization, intensive agriculture and mining activities began to leave massive footprints on the regional environment. In more recent decades, water bodies in the region have been massively modified by both water withdrawals and pollutant influxes. At the example of the Lake Baikal, Aral Sea, and Tarim River basins, this paper provides an overview of the impacts of human activities on the large rivers and receiving (terminal) lakes in Central and Eastern Asian drylands. Finally, recent measures to at least partially restore their aquatic ecosystems are analyzed.



## 1. Introduction

The drylands of Central and Eastern Asia are home to several major river systems and lake basins, many of which are endorheic, including the Amu Dary–Syr Darya–Aral Sea Basin, the Ili River–Lake Balkhash Basin, the Kherlen-Lake Hunlun Basin and the Tarim-Lop Nur Basin. And while its basin is not endorrheic, it may seem surprising that Lake Baikal, the world's largest lake by volume, has significant parts of its basin covered by drylands.

The hydrology and ecology of Central and East Asian dryland rivers and lakes are very closely linked to their catchments. As one of the world's most continental regions, Central Asia is located between the Caspian See to the west, China to the east, Russian Siberia to the North and the Himalayas to the South. The Central Asian drylands extend into the western part China, which is similarly arid and continental. The climate in these region is characterized by extremes such as massive temperature amplitudes (up to 90 K), limited precipitation (typically between 100 mm and 400 mm per year) and high rates of potential evaporation (more than 900–1500 mm per year) (Bai et al., 2012; Karthe et al., 2014; Menzel et al., 2011). 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). Over the past few decades, the continental drylands of Central and Eastern Asia have been warming almost twice as fast as the global average. Since this trend is expected to continue, water abstractions for irrigation are expected to further increase in the future (Karthe et al., 2014; Malsy et al., 2015; Törnqvist et al., 2014).

### 1.1. Relevance of high mountain zones

High-mountain zones play a vital role for the water supply in Central Asia's vast lowlands (Lutz et al., 2013; Minderlein and Menzel, 2015; Savoskul and Smakhtin, 2013; Sorg et al., 2012; Unger-Sayesteh et al., 2013). Mountain regions act as “water towers” with a high relevance for runoff and groundwater generation (Farinotti et al., 2015), and both glaciers and snow pack provide an intermediate storage of water resources. One of the most

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http://dx.doi.org/10.1016/j.quaint.2017.01.041
1040-6182/

extreme examples is the Tarim River, which is almost entirely fed by precipitation in its mountainous headwater zone, which sharply contrasts with the hyperarid deserts further downstream (Keilholz et al., 2015).

While glaciers 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; Kriegel et al., 2013; Unger-Sayesteh 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., 2013). 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, glacier melt contributes 18% to 28% to annual runoff and up to 70% to summer runoff (Aizen et al., 1996; Dikich and Hagg, 2003).

The Tien Shan, which is among the main glaciated regions of Eurasia, has a glacierized area of about 16,000 km$^2$, of which approximately half is located in Kyrgyzstan (Khromova et al., 2014; Sorg et al., 2012). In the Pamir, there are more than 10,000 glaciers with a total glacierized area of almost 10,000 km$^2$ (Khromova et al., 2014). The Altai is much less glacierized, with more than 1500 glaciers covering between 1000 km$^2$ and 1600 km$^2$ according to different estimates (Khromova et al., 2014; Shahgedanova et al., 2010). However, glacial dynamics and their hydrological implications are poorly studied in several high mountain areas of Central Asia, largely because they are located far from human settlements (Fedotov and Margold, 2015).

Besides glaciers, mountain forests play a key role for freshwater generation, which is much greater than in sparsely vegetated steppe areas (Minderlein and Menzel, 2015). Forest fires have been identified as a particular threat, because they significant reduce the water storage and retarding capacity (Kopp et al., 2016) and accelerate permafrost degradation (Kopp et al., 2014). The combined effects of lower soil water storage capacities, higher soil temperatures/permafrost degradation and increased drainage along hill slopes leads to a progressive desiccation of soils which limits post-fire taiga regrowth and leads to vegetation regime shifts towards grassland species and deciduous trees (Dulamsuren et al., 2005; Dulamsuren and Hauck, 2008; Tchebakova et al., 2009). Even under normal conditions, a complete recovery of forests affected by fires can take 200–400 years, particularly with regard to the recovery of late successional conifers (Goldammer, 2002; Schulze et al., 2005).

### 1.2. Specific characteristics of dryland streams and lakes

Drylands are home to a very large variety of water bodies, including some of the largest lakes (e.g., Caspian Sea, Lakes Aral, Chad, Balkhash, Eyre and Torrens) in the world, several of which are located in or at the fringe of Central Asia such as the Caspian Sea, Lake Aral, Lake Balkash and Lake Baikal (Williams, 2000).

The **irregularity of flow** is a key difference between dryland rivers and their counterparts in more humid regions (Davies et al., 1994; Molles et al., 1992; Walker et al., 1995), because it has direct effects on their physical habitat template (Karthe et al., 2015a; Poff and Ward, 1989, 1990), including channel morphology, sediment and matter transport processes (Chalov et al., 2015, 2016; Graf, 2011), and aquatic and floodplain biology (Junk et al., 1989; Karthe et al., 2015a). In contrast to equilibrium channel conditions that are predominant in humid regions, the channels of dryland rivers tend to change constantly due to extreme changes in water and sediment loads (Davies et al., 1994). Moreover, many dryland rivers are allogenic, originating from relatively well-watered areas and then passing through semi-arid or arid landscapes with little runoff contribution (Walker et al., 1995) so that runoff can actually reduce further downstream in the basin (Finlayson and McMahon, 1988). Intermittent streams and rivers are characterized by a more or less regular discharge that seasonally ceases. They typically have a water flow for 20%–80% of the time. Ephemeral (or episodic) streams and rivers only flow after major precipitation events and flow for less than 20% of the time (Matthews, 1988). Temporary flow in dryland rivers has a special biological significance, because the cessation of flow interrupts river continuity and modifies the food and oxygen supply, thermal environment and substratum, thereby eliminating certain species. Colonizers that are adapted to temporary streams are therefore characterized by a tolerance of extreme conditions (dessication), high mobility, opportunistic reproduction and rapid development (Davies et al., 1994).

Even when river flow is not temporary, hydrological variability tends to be strong due to highly variable precipitation and low rainfall-runoff ratios. While the sporadic nature of precipitation increases towards the interior of continental regions, the percentage converted to runoff decreases (Thoms and Sheldon, 2000).

As an 'aquatic-terrestrial transition zone' (Junk et al., 1989), the **floodplains of dryland rivers** undergo distinct drying and wetting cycles. While the biomass and productivity of dryland floodplains depend directly on discharge and flooding, even under inundation they markedly differ from the (more) permanent aquatic environment. Similarly, their 'terrestrial phase' is clearly distinguished from terrestrial habitats outside the floodplain (Davies et al., 1994).

### 1.3. Significance and anthropogenic modification of dryland rivers and lakes

Water bodies in drylands have a significance for local populations that typically exceeds that of their counterparts in more humid regions, including a high relevance for Irrigation and fisheries; aesthetic appeal and cultural significance; and educational values by rapidly showing impacts of human impacts (Williams, 2000). Very often, dryland rivers and lakes frequently constitute “the only exploitable water resources” in their region (Davies et al., 1994:484), and “water flowing to the sea is often perceived as a 'wastage' of an essential resource that should be stored and manipulated for the benefit of people” (Davies et al., 1994:500).

In regions of low and variable rainfall, surface water bodies are exploited significantly, but scientific data on the hydrological response to water abstractions and flow regulations are limited. However, the physical and biological changes induced by hydrological change in dryland rivers differ strongly from those in temperate rivers (Braune, 1985; Davies et al., 1994; Thoms and Sheldon, 2000; Thoms and Walker, 1993). Regulation modifies a key feature of dryland rivers, namely their flow variance (including the timing, frequency and magnitude of floods and low flows), with the result that their often unique natural fauna and flora “converge towards a global standard”, thereby reducing regional and global biodiversity (Davies et al., 1994; Walker et al., 1995:99). This process is intensified by interbasin water transfers (Davies et al., 1994). In combination, flow regulation and interbasin water transfers frequently lead to an influx of invasive species and a mixing of population gene pools (Davies et al., 1994).

Cascades of dams and reservoirs are common means of flow regulation and water management in drylands. One important challenge for reservoir operation is sedimentation, which is reported to result in reservoir capacity losses of about 0.5% to more