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EDITORIAL

Environmental change in the Selenga River—Lake Baikal Basin

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Introduction

Lake Baikal's most important tributary is the Selenga River, which contributes about 50 to 60% of its surface water influx (Chalov et al. 2015; Opp 1994; Törnqvist et al. 2015). Moreover, the Selenga's 447.060-km^2 watershed covers 82% of the Lake Baikal Basin (Nadmitov et al. 2014) (Fig. 1), which means that any environmental changes along the Selenga and its tributaries may ultimately impact Lake Baikal. However, north of the Buryatian capital Ulan Ude, the Selenga River branches into the largest freshwater inland delta in the world (Logachev 2003). The associated wetland constitutes a unique ecosystem (Гармаев and Христофоров 2010) and acts as the final geobiochemical barrier before the Selenga discharges into Lake Baikal (Chalov et al. 2016). Therefore, it has a great impact on pollution delivery to Lake Baikal, storing up to 60–70% of the sediment load of the Selenga River (Chalov et al. 2017).

The protection of Lake Baikal and the planning of water management measures in the Selenga river basin require a good understanding of current trends regarding hydrology, water quality, aquatic and riparian zone ecology of the Selenga and its key tributaries (Karthe et al. 2016), and geo- and biochemical processes governing the ecological functioning of the Selenga delta (Khazheeva et al. 2004). The following anthropogenic impacts constitute threats to the ecology of the Selenga from its tributaries down to its delta:

Various mining activities are found in the Selenga river basin, including the exploitation of coal, gold, copper, molybdenum and wolfram (Sandmann 2012; Timofeev et al. 2015). As a consequence, elevated levels of heavy metals and other mining-related pollutants (cyanides, phosphorus) have been detected in the water and sediments of the Selenga and its tributaries, as well as floodplain soils and groundwater (Battogtokh et al. 2014; Brumbaugh et al. 2013; Chalov et al. 2015; Inam et al. 2011; McIntyre et al. 2016; Nadmitov et al. 2014; Pavlov et al. 2008; Pfeiffer et al. 2015; Stubblefield et al. 2005; Thorslund et al. 2012). Even though contaminant transport towards the Selenga delta does take place (Chalov et al. 2015; Khazheeva et al. 2004; Karthe et al. 2014), it should be noted that contaminations currently have the largest effects in local hot spots (Hofmann et al. 2010; Inam et al. 2011; Pfeiffer et al. 2015). Currently, there are different views regarding their impact on Lake Baikal itself (Chebykin et al. 2010; Pavlov et al. 2008). However, bioaccumulation and toxicological effects observed in aquatic biota ranging from insects to fish provide indication that water quality deterioration in the Selenga river system does have an ecological impact (Avlyush 2011; Kaus et al. 2016; Komov et al. 2014).

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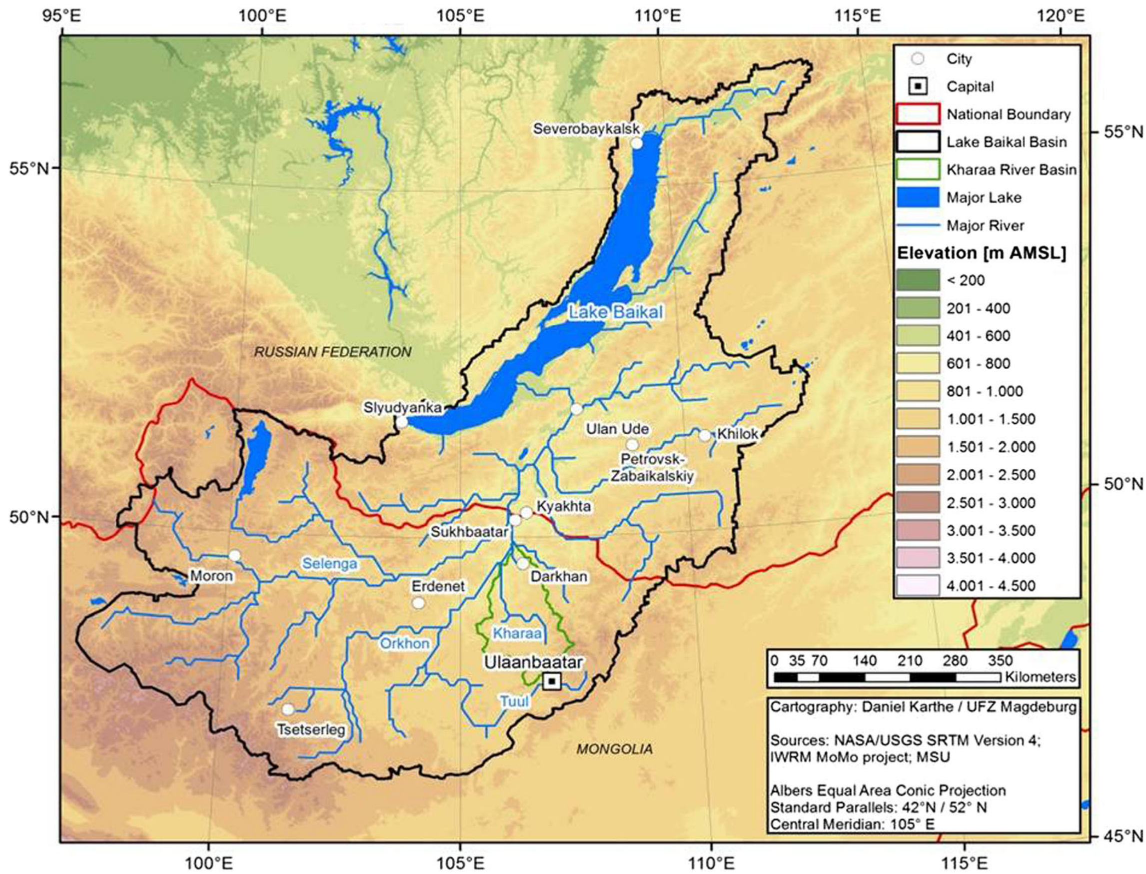

Fig. 1 Map of the Selenga River—Lake Baikal Basin

Urban wastewater inputs are another major stressor for the Selenga and its tributaries. A large part of the Selenga river basin's population is concentrated in four cities. The three largest cities of Mongolia (Ulaanbaatar, Erdenet and Darkhan) as well as Ulan Ude, the capital of the Republic of Buryatia in Russia, are located on the Tuul, Orkhon, Kharaa and Selenga rivers, respectively. These urban areas have multiple impacts on the region's water resources. Firstly, per capita water consumption in urban areas is considerably higher than in peri-urban or rural regions (Scharaw and Westerhoff 2011; Sigel et al. 2012). Secondly, poor wastewater treatment infrastructures lead to nutrient inputs (Hofmann et al. 2010, 2011; Karthe et al. 2016) and microbiological contamination of rivers (Sorokovikova et al. 2013). Thirdly, urban areas in the Selenga river basin are characterized by a concentration of pollutants originating from the combustion of fuels and various industries (Dalai and Ishiga 2013; Kasimov et al. 2011; Opp 2007; Pfeiffer et al. 2015; Sorokina et al. 2013; Kasimov et al. 2016), some of which enter the water cycle directly or via atmospheric deposition.

Land use change, which is currently more pronounced in the Mongolian than the Russian part of the Selenga river basin, is driven chiefly by mining and the expansion of agriculture (Mun et al. 2008; Priess et al. 2011). The conversion of forests and natural grasslands into pastures and fields has implications for both hydrology (Minderlein and Menzel 2015) and water quality, chiefly by stimulating erosion processes (Priess et al. 2011; Theuring et al. 2013, 2015).

Present and expected hydrological changes in the Selenga river basin are caused by three processes: land use changes (Karthe et al. 2015; Minderlein and Menzel 2015), the impacts of global climate change on precipitation and evaporation (Hampton et al. 2008; Magnuson et al. 2000; Malsy et al. 2016; Törnqvist et al. 2015) and permafrost (Moore et al. 2009; Törnqvist et al. 2015), and increasing water withdrawals. The latter are related to the expansion of agriculture and rising irrigation needs in the context of global warming (Malsy et al. 2016; Priess et al. 2011) and in the future, potentially due to water diversions into mining areas in the South Gobi (Sorokovikova et al. 2013).

About this Special Issue

This Special Issue aims at providing insights into recent research activities into environmental change in the Selenga-Baikal Basin. The results of the various international research programs such as the Russian Geographical Society project "Expedition Selenga-Baikal", UNDP-GEF project "Integrated Natural Resource Management in the Baikal Basin Transboundary Ecosystem", and the German BMBF-funded projects "Integrated Water Resources Management: Model Region Mongolia" and "Modelling of Water Quantity and Quality in the Selenga-Baikal Region: Current Potentials and Future Necessities" contributed to it.

Thematically, the manuscripts consider hydrological changes and their drivers, pollutant and sediment input, transport and deposition and their role for the aquatic ecosystem of the Selenga, its tributaries and its delta. The spatial focus of the manuscripts ranges from basinwide studies (Malsy et al. 2016; Frolova et al. 2017) to specific subregions such as the Selenga's headwaters (Kopp et al. 2016; Kaus et al. 2016; Thorslund et al. 2012) or its delta (Chalov et al. 2016) (Table 1). These studies provide an important contribution for a better understanding of spatial and temporal processes regarding hydrology, sediment and pollutant fluxes and aquatic ecology in the Selenga River—Lake Baikal Basin, adding novel insights into this unique ecosystem as compared to previous reports in literature (Table 1).

Various temporal scales have been considered, ranging from the identification of long-term changes in the past based on hydrological and meteorological datasets (since the 1930s) (Frolova et al. 2017) or in the future based on scenarios and bias-corrected climate input (Malsy et al. 2016). Using hydrological and meteorological station data (since the 1930s), remote sensing and statistical analyses, Frolova et al. (2017) estimated long-term changes in annual average flow, annual maximum hourly flows and annual minimum 30-day flows. Compared to the historical period 1934–1975, the most recent period 2002–2014 showed a significant flow reduction of 30%, in comparison with a moderate average reduction of 12% for the longer period 1976–2014. Malsy et al. (2016) focused on the question whether climate change or socioeconomic change in the Selenga river basin is the more important driver of water quality changes in the region. The authors conclude that population growth/urbanization and increasing industrial activities (particularly mining) have the strongest impact on the water quality parameters considered in this study (biological oxygen demand, total dissolved solids, instream coliforms). The observed and predicted water quality deterioration is at least partly reinforced by climate change.

The role of environmental changes for the local to regional scale hydrology were investigated by Kopp et al. (2016) who assessed the impacts of wildfires on infiltration and runoff-forming processes in a Mongolian headwater area of the Selenga river system. The authors found that the impacts on forest fires on organic soil layers reduce its water retention capacity, leading to increased stormflow but decreased baseflow and thus negative effects on water availability further downstream during dry periods. The opposite end of the river system is the focus of an integrated study of the Selenga River delta, which assessed metal accumulation in bottom sediments and plants, heavy metal budgets and water and sediment partitioning (Chalov et al. 2016) with a focus on long-term and seasonal variations. In order to explain recent changes in the delta and its barrier functions, the authors addressed spatiotemporal changes in water flow, morphology and transport of sediments both in the upstream Selenga River system and the delta itself.

Snapshot field measurements of heavy metals in water and sediments (Thorslund et al. 2012) and fish communities (Kaus et al. 2016) were conducted to assess river system change

Table 1 Some examples of reported spatial and temporal resolutions of environmental processes in Selenga River—Lake Baikal Basin

Spatial scale	Temporal scale			
	Snapshot characterization	Seasonal variations	Long-term past changes	Long-term future predictions
Selenga catchment	Metals and other elements in streambed sediment and floodplain soil (Brumbaugh et al. 2013)	Sediment transport (Chalov et al. 2015), heavy metal fluxes (Lychagin et al. 2017)	Annual average flow, annual maximum hourly flows and annual minimum 30-day flows (Frolova et al. 2017)	Water quality parameters (Malsy et al. 2016)
Selenga river tributaries/subcatchment	Heavy metal and arsenic accumulation in five fish species (Kaus et al. 2016)	Stormflow and decreasing low-flow condition headwaters (Kopp et al. 2016)	Sediment budget in the Kharaa River basin (Theuring et al. 2015)	n/a
Local hot spots (Tuul and Sharyngol rivers)	Multiple metals and their partitioning (Thorslund et al. 2012) Heavy metal pollution of soils and snow in cities and mining areas (Kasimov et al. 2016)	Soil erosion and sediment and heavy metals delivery (Pietroń et al. 2017)	Dissolved and total heavy metals (Thorslund et al. 2012)	n/a
Selenga delta	Heavy metals in water and bottom sediments (Khazheeva et al. 2004)	Heavy metal budget, metal accumulation in bottom sediments and plants (Chalov et al. 2016)	Water partitioning and sediment budget (Chalov et al. 2016)	n/a

Grey columns indicate studies reported in this special issue

n/a no studies have been performed on the topic related to mining developments in Kharaa and Tuul river in the upper to central Selenga river basin. Based on an equilibrium geochemical model, Thorslund et al. (2012) revealed that several metals (Al, Cd, Fe, Mn, Pb and V) are exported from mining sites to the downstream river system, as shown by net increasing mass flows. The study also focused on the importance of predicting potential future changes in the bioavailable dissolved fractions under changing ambient conditions from a health risk perspective. Kaus et al. (2016) examined the spatial pattern of heavy metal contamination in fish in the meso-scale Kharaa river basin, which is located in the central part of the Selenga-Baikal basin. The authors reported heavy metal and arsenic accumulation in five fish species sampled, particularly in the middle and lower reaches of the river. They found about a tenth of the river fish to contain mercury at levels above recommended thresholds for human consumption.

The reported regional environmental change in the Selenga River—Lake Baikal Basin is one important basis for water resources management planning with the aim of achieving a sustainable use of water resources by reducing pollution of the aquatic ecosystem for the Selenga. While the research results contained in this thematic issue imply significant advances on the current state of knowledge, Table 1 also reveals needs for future research by identifying combinations of thematic issues, spatial and temporal scales that have not yet been analysed in the area. In particular, a better understanding of pollution impacts on the aquatic ecosystem of the Selenga and its delta based on future pollution scenarios is crucial in order to identify potential tipping points of this system which could lead to much greater contaminant fluxes into Lake Baikal.

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