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INTEGRATING MULTI-SCALE DATA FOR THE ASSESSMENT OF WATER AVAILABILITY AND QUALITY IN THE KHARAA – ORKHON – SELENGA RIVER SYSTEM

ABSTRACT. The environmental and socio-enonomic impacts of water pollution are particularly severe in regions with relatively limited water resources [WWAP, 2012]. Water quantity and quality are closely interlinked aspects which are relevant for surface water ecology, water use, and integrated management approaches.

However, an intensive monitoring of both is usually prohibitive for very large areas, particularly if it includes the investigation of underlying processes and causes. For the Kharaa – Orkhon – Selenga River system, this paper combines results from the micro (experimental plots, individual point data), meso (Kharaa River Basin) and macro (Selenge River Basin) scales. On the one hand, this integration allows an interpretation of existing data on surface water quantity and quality in a wider context. On the other hand, it empirically underpins the complimentary character of intensive monitoring in selected model regions with more extensive monitoring in larger areas.

KEY WORDS: hydrology; water availability; water quality; Central Asia; Mongolia; Russia

INTRODUCTION

The Kharaa, Orkhon and Selenga rivers (Table 1), which are located in northern Mongolia and southern Siberia, are not only parts of the same major river system draining into Lake Baikal, but their basins are in many ways comparable with regard to the physical environment and socio-economic development [Karthe et al., 2013]. Due to its moderate size (15 000 km^2), the Kharaa River Basin could be intensively studied in the context of a German-Mongolian research project which aimed at the development of the scientific basis for a locally adapted IWRM concept [MoMo Consortium, 2009; Karthe et al., 2012]. The Kharaa River originates at the confluence of Mandalin Gol and Sugnugur Gol, draining from the western parts of the Khentii mountains. It is a tributary of the Orkhon River, into which it flows just downstream of Darkhan, Mongolia's second largest city. The Orkhon River is Mongolia's longest stream, and some of its tributaries, most notably the Tuul and the Kharaa Rivers, meander through the country's most densely settled regions. A River Basin Management Plan which was recently developed in cooperation between the Mongolian environmental ministry and a Dutch consultancy project provides an overview of existing information (and knowledge gaps) for this basin[MEGD, 2012]. Near Sukhbaatar and just before the Russian-Mongolian border, the Orkhon River drains into the Selenga, which then flows northward and forms a wide delta before draining into Lake Baikal [Kasimov et al., 2010]. Synoptic research on the Selenga River Basin was recently carried out by research projects involving Russian, Mongolian, Swedish and Korean scientists [Chalov et al., 2012; Thorslund et al., 2012; Mun et al., 2008].

WATER AVAILBILITY AND ITS DETERMINANTS

The northern part of Mongolia and the southern part of Siberia, where the Kharaa – Orkhon – Selenga river system is located, are characterized by a highly continental climate with very cold winters and a limited natural water availability [Menzel et al., 2011]. The potential evapotranspiration exceeds the annual precipitation by a factor of almost 3. This chapter first summarizes important links between climate and water availability in the region, including the impacts of climate change, which are expected to be stronger

Table 1. Characteristics of the Kharaa, Orkhon and Selenga river basins

	Kharaa	Orkhon	Selenga
Length of river	362 km	1066 km	1 024 km (1453 km incl. Ider)
Catchment area	Ca. 15 000 km^2	Ca. 54 000 km^2	Ca. 450 000 km^2
Average runoff near outlet (MQ)	12.1 m^3/s	124.5 m^3/s	897 m^3/s
Population	Ca. 147,000 inhabitants	Ca. 236 000 inhabitants	Ca. 2 439 000 inhabitants

Sources: Mun et al., 2008; MoMo Consortium, 2009; Garmaev et al., 2010; Potemkina, 2011; Kasimov et al., 2010; MEGD, 2012; Thorslund et al., 2012 for East-Central Asian drylands than in other parts of the world [IPCC, 2007]. The following section addresses hydrological trends observed in different parts of the river system and demonstrates that the meso-scale Kharaa River Basin is a suitable model region for the macro-scale Selenga River Basin. For this model region, a third subchapter analyzes the dynamics of land use change at river basin scale, including their hydrological relevance. A more detailed discussion of hydrometeorological processes and landcover in the basin's headwater region is presented in the chapter's last section.

Water Availability in the Selenga – Baikal Basin and Expected Impacts of Climate Change

The Central Siberian Plateau, including the Lake Baikal Basin, is one of the regions where the effects of global climate change are particularly marked [Clarke et al., 2007]. Mean annual air temperatures increased in the lake area by 1,2K during the 20th century. The air temperature change over the entire river basin is probably higher due to the balancing impacts of the Lake Baikal water body. During the same time, mean annual precipitation increased by 59 mm, both with a considerable regional and interannual variability. On the one hand, this led to an inflow increase of 17% during the last century. On the other hand, both ice duration (–11 days) and ice thickness (–24 cm) on Lake Baikal decreased notably during this period [Shimaraev et al., 2002].

In order to assess the regional pattern and trends of water availability, (1) recent freshwater resources were simulated using the WaterGAP3 model (Water – Global Assessment and Prognosis) and WATCH forcing data and (2) changes in temperature and precipitation were shown for 2071 to 2100 using WATCH driving data based on three global circulation models (GCMs). The simulation of recent freshwater resources (baseline time period 1971–2000) was conducted with the large-scale hydrology and water use model WaterGAP3. WaterGAP3 is a further development of WaterGAP2 [Alcamo et al., 2003; Döll et al., 2003] and operates on a five arc minute grid (~6×9 km^2) in daily internal time steps [Verzano, 2009]. In this study a landmask derived from river basins for the Lake Baikal river system has been applied. The calibration and validation of the model was done with the global meteorological dataset WATCH forcing data (WFD). The WFD is based on a half degree grid in daily time steps [Weedon et al., 2011] and was rescaled to the model resolution of five arc minutes. The water use model contains five sub models for the calculation of water abstractions in the sectors irrigation, livestock, domestic, manufacturing, and thermal electricity production [aus der Beek, 2010; Flörke, 2013]. As scenario data for the time period 2071–2100 the WATCH driving data (WDD) set was used, which consists of transient bias corrected climate change projections. This dataset is available for the A2 and B1 IPCC-SRES Scenarios (IPCC 2000) and three GCMs (IPSL, ECHAM5 and CNCM3) [Hagemann et al., 2011; Piani et al., 2010].

Modelled mean annual water availability of Lake Baikal inflows (Fig. 1) shows the lowest water availability in the Tuul and Khilok river basins, while the upper Angara catchment features the highest water availability. The mean annual water availability for the Lake Baikal Basin is 83 mm, but with a large regional variation. This is due to mean annual air temperatures ranging from –11,4°C to +1,0°C, and mean annual precipitation ranging from 188 mm to 872 mm. Both the A2 and B1 scenario predict an increase of precipitation (ranges 241 mm to 1109 mm and 211 mm to 1015 mm, respectively) until the end of 21st century. The highest increase is predicted for the southern shore of Lake Baikal, while the lowest increase is expected for the Tuul river basin according to the A2 scenario and in the headwater region of the Ider and Chuluut rivers according to the B1 scenario. Both scenarios predict a significant rise of mean annual air temperature for the entire Lake Baikal basin (ranges from –6,2 to +6,5°C for A2, and –8,2 to +4,5°C for B1).

This substantial temperature and precipitation increase is likely to have various direct and indirect effects on regional hydrology, such as increasing evapotranspiration, permafrost thawing, and decline of the snow layer. Anisimov & Reneva [2006] expect that the area of near-surface permafrost will decrease by 18% until 2050. Using simulations based on the WaterGAP3 model, Malsy et al. [2012] have shown for the Mongolian part of the basin that water availability will increase until the end of the

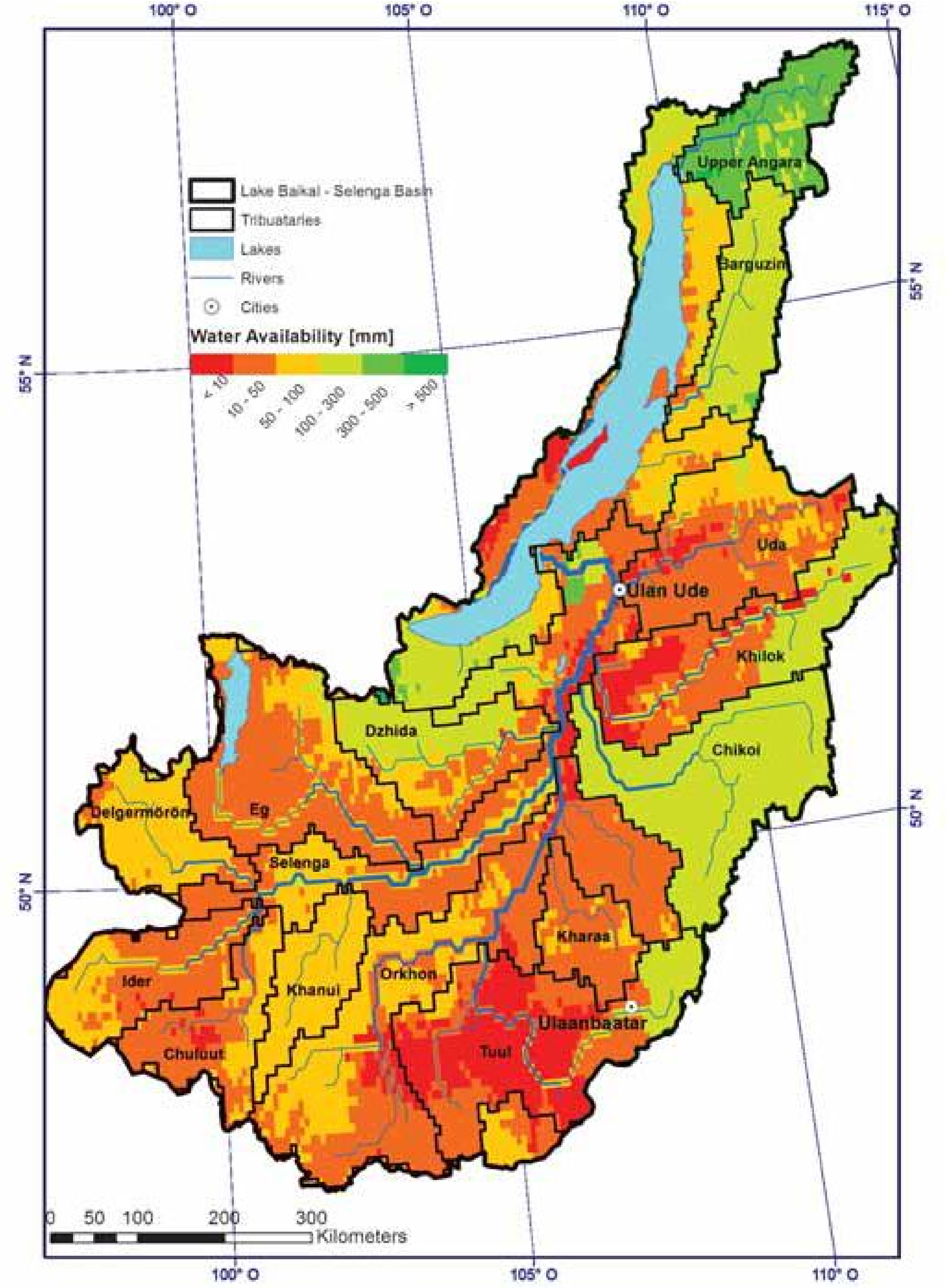

Fig. 1. Modelled mean water availability in the Selenga-Baikal Basin (1971–2000).

21st century. Similarly, a realistic estimate for future water availability in the entire Selenga – Baikal Basin would need to be based on a model capable of recognizing the interplay of different drivers (such as changes in temperature, precipitation and land use). One particular challenge in the context of this transboundary catchment is differences in the quality and availability of input data for the Mongolian and Russian parts of the basin.

Hydrological regime of the Kharaa – Orkhon – Selenga River System

Despite considerable differences in absolute discharge quantities, the Kharaa, Orkhon and Selenga Rivers show a large interannual uniformity in their discharge pattern (Table 2). The hydrograph of all three rivers is characterized by very low winter discharge and two major runoff periods in April/May and July/August.

Stream flow increases rapidly from March to April and is related to thawing processes affecting snow cover, water in the soil and the subsurface, and groundwater stored in icings [Sloan & Van Everdingen, 1988; Woo et al., 2000]. For the Kharaa River Basin, Wimmer et al. [2009] estimated that the melt of snow covers contributes only 5–6 mm to runoff due to the high sublimation rates. As snow melt cannot make up the entire stream flow during spring, the remaining part must be formed by soil and subsurface water as well as by the melting of aufeis. Since soils and the shallow subsurface are depleted at first, only small volumes of excess water in the soils are expected to remain in spring. This points to the importance of river icings. It is known that ice shields on subarctic rivers strongly contribute to spring discharge [Hu & Pollard, 1997]. As melting progresses, the discharge rate gradually increases. This is consistent with the exponential increase of observed stream flow. Once snow and ice have melted in May, river discharge decreases.

With the beginning of the summer rainfall period in June and July, stream flow rises instantly in response to precipitation events. Rainfall in summer contributes mainly to groundwater flow and less to direct flow. Contrastingly, the melt of snow covers produces a considerable amount of direct runoff. The reason for that is that the infiltration and water holding capacity of the soils is increased when the active layer thaws in summer [Bolton 2006]. During that time, the water storages in the subsurface are filled. For the Kharaa, Orkhon and Selenga, about half of the annual runoff occurs during the summer season (June–August). Therefore, a chief cause for the variations in the runoff is the variability of summertime precipitation [Berezhnykh et al., 2012]. From October on, when temperature drops below 0°C, snow becomes the dominant form of precipitation. Relatively low amounts of snowfall result in the depletion of groundwater and soil storages and the exponential decrease of stream flow in late autumn and winter.

Table 2. Seasonality of discharge for the Kharaa, Orkhon and Selenga Rivers

River	Period	Mean annual runoff, m^3/s	Mean contribution of quarterly runoff to total annual runoff			
			Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec
Kharaa at Baruunkharaa	1951–2001	10,71	3,8%	31,5%	51,0%	13,6%
Orkhon at Sukhbaatar	1950–2008	124,5	1,7%	29,8%	53,8%	14,7%
Selenga at Kabansk	1971–2009	863,77	3,5%	29,5%	51,3%	15,6%

Sources: Mongolian Institute of Hydrology and Meteorology; MEGD, 2012; Russian Federal Service for Hydrometeorology and Environmental Monitoring – Roshydromet

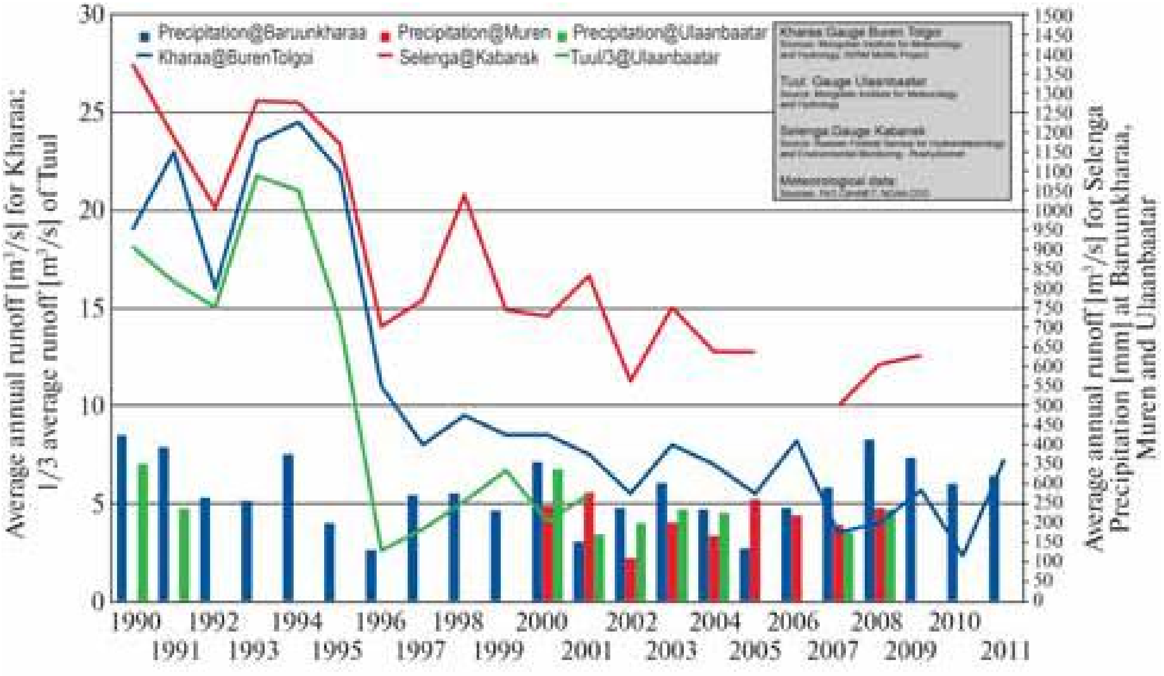

Fig. 2. Annual precipitation and runoff in the Kharaa, Tuul and Selenga Basins.

Interannual variations of the Selenga basin's renewable water resources are significant (Fig. 2). For the SelengaRiver and its western tributaries (Muren, Eg, Dzhida, Temnik), the mean annual flow is 2–3 times higher in high-discharge years as compared to low-water years. For the Selenga's eastern tributaries (Orkhon, Tuul, Chikoj, Khilok, Uda) this factor ranges between 4 and 5 [Semenov & Myagmarzhav, 1977].

The low density of gauges and meteorological stations, data gaps and uncertainties related to data quality make it difficult to analyze the links between interannual precipitation and runoff dynamics. At first sight, it seems that the five year periods from 1990 to 1994 and from 2007 to 2011 were similarly wet in the Kharaa River Basin (Fig. 2; on average, 343 mm and 338 mm total annual precipitation at Baruunkharaa meteorological station, located in the center of the Kharaa River Basin respectively; long-term mean: 294 mm). In contrast, annual runoff of the Kharaa, measured at the basin outlet at Buren Tolgoi, was comparatively high from 1990 to 1994 (21,4 m^3/s) and comparatively low from 2007–2011 (4,5 m^3/s; long-term mean: of 12,4 m^3/s).However, the distribution of precipitation in the region is known to be inhomogeneous [Menzel et al., 2011; Berezhnykh et al., 2012]. Keeping in mind the above mentioned data limitations, interpolated meteorological station data from the Global Precipitation Climatology Center suggest that the years between 1996 and 2011 were characterized by negative precipitation anomalies throughout most of the Selenga River Basin [Berezhnykh et al., 2012]. This would explain the significant decrease in mean annual discharge in the Kharaa, Selenga and Tuul between the first and the second half of the 1990s (Kharaa: –44%; Tuul: –65%; Selenga: –28%). Moreover, the second half of the 1990s was characterized by longer than usual heat waves in the summer, and the warmest year of the century in Mongolia in 1998 [Batimaa et al., 2005]. Higher evapotranspiration therefore appears to be another plausible reason for a reduction in runoff formation.

Land Use Changes and their Hydrological Relevance in the Kharaa River Model Region

In the Kharaa River Basin (KRB), approximately 62% of the land is covered by grassland, 28% by forest, 9% by cropland and 1% by settlements (Fig. 3). Land use, which is spatially still dominated by grazing, is characterized by rapid changes in the recent past. Since the turn of the century, lifestock population has doubled and a similar development can be observed in agriculture since 2006/7. While the sawn area currently sums up to 50,000 ha, the total area under cultivation including fallows for crop rotation amounts to 110,000 ha. Simultaneously, the national government provides financial incentives to intensify production, based on the "3rd Campaign of re-claiming virgin lands" with the final objective to achieve food self-sufficiency [Priess et al., 2011]. At the same time, favourable market conditions in Ulaanbaatar and Darkhan seem to drive the fast expansion of vegetable production. The observed changes of the recent past imply several direct and indirect hydrological consequences. In terms of land

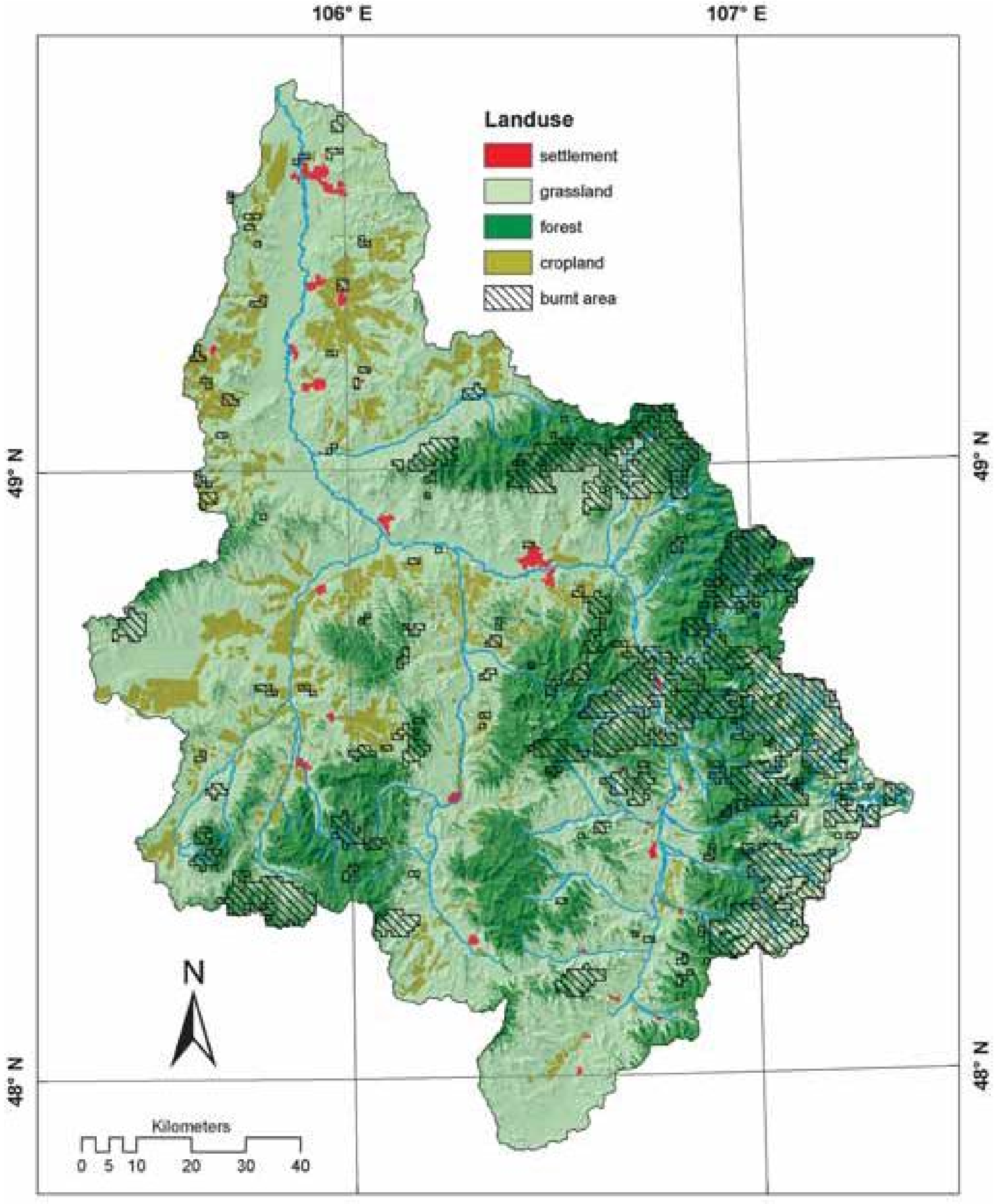

Fig. 3. Land cover map derived from Landsat TM for the year 2010, including areas affected by wildfires (MODIS).

use, an increased competition for fertile and accessible land between herders and farmers can be observed, resulting not only in strongly increased fencing of fields, but also in expanding agricultural production from the river plains and valleys towards less favourable sloping lands and higher elevations. It can be assumed that the doubled livestock population causes degradation of grasslands, thereby altering not only biomass productivity but also evapotranspiration and runoff [Ishii & Fujita, 2013]. All vegetable producers, and an increasing number of wheat and potato producers irrigate their land, currently 5,000–6,000 ha. Depending on which assumptions we make for the ratios of different irrigation technologies in use (flooding, sprinklers, drip irrigation), the amount of water used for irrigation is in the range of 22–28 mio. m^3 per year for the entire catchment. While government plans aim at doubling the area of irrigated areas to 10,000 ha, our scenarios based on more moderate rates of expansion observed in the past, result in 7000–8000 ha of irrigated land until 2050. Depending on irrigation area and the use of (improved) technologies, we expect an increase in water use to 35 to 45 mio. m^3. This figure compares to an average of 80 mio. m^3 during dry years.

While agricultural land use alters hydrological processes and currently emerges as an important consumer of water, a considerable part of the Kharaa's headwater regions, particularly in the eastern part, is still forested (Fig. 3). Besides the relevance for the water regime, Mongolian forests play an important role in preventing soil erosion, maintaining permafrost distribution and providing wildlife habitats [Tsogtbaatar, 2004]. However, deforestation is increasing due to the growing livestock numbers, increased demand for wood (timber and firewood) and increased occurrence of wildfires of anthropogenic origin. In addition, the rate of natural re-growth and successful reforestation is far too low and protection efforts often lack success due to inefficient management strategies and deficits regarding law enforcement [Tsogtbaatar, 2013]. Satellite based detection of wildfires based on MODIS fire data [Giglio et al., 2003] indicates that in total 200 000 ha (which equates about 14% of the forested area) have been affected by wildfires to a varying degree between April 2000 and May 2012 (Fig. 3). The quantification of hydrological implications of gradual and abrupt forest cover changes is generally difficult and requires careful exploration of hydrological components such as evapotranspiration, infiltration, runoff formation and water holding capacity.

A third important driver of landuse change in the region are mining activities. Especially gold mining requires large amounts of (ground-)water, which larger companies reuse from sedimentation ponds, while smaller companies and illegal extractors tend to use river water with motor pumps and open sedimentation cascades, with most of the used (and contaminated) water remaining in the catchment. The ponds are considered the key sources of net water losses from mining via evaporation (assuming well sealed ponds). In years of normal precipitation, the evaporation from open water surfaces of artificial lakes for irrigation and sedimentation ponds of gold mining companies combined (about 4.6 mio m^3 from ~550 ha water surfaces) sum up to about 1% of the long-term river discharge, a value that may double or triple in dry or hot years with higher evaporation and reduced river discharge (see Fig. 2).

Investigation of Hydrometeorological Processes in a Headwater Region and their Relevance at River Basin Scale

Since a major part of the KRB lacks environmental information, hydrological investigations initially had to be based on few meteorological data from official stations, a time series of observed discharge at the basin outlet and the application of a robust hydrological model approach [Törnros & Menzel, 2010]. After calibration, the model was applied to predict the water balance in the ungauged sub-catchments. As expected, the headwaters of the basin appear to act as regional water towers where substantial discharge volumes are produced [Menzel et al., 2011]. This is in sharp contrast to the dry steppe forelands with low to absent discharge formation.

Based on these findings, extensive field investigations were carried out in a mountainous sub-basin of the Kharaa. The Sugnugur river drains parts of the remote Khentii Mountains which stretch in the east of the Kharaa catchment and peak at about 2,800 m a.s.l. This sub-catchment includes the transition belt between the steppe, taiga and alpine ecotones and therefore includes a variety of environmental factors, e.g. snow storage, permafrost occurrence [Ishikawa et al., 2005] or forest distribution, which determine hydrological processes, water quality and water availability. Parts of the region represent a pristine boreal and mountain environment. It is assumed that they act as the major freshwater generating areas of the Kharaa catchment. However, there are several indicators of human impacts and climate variability on the ecosystem, the most serious are forest fires, leaving extensive areas with burned forest.

In 2011, a monitoring program was started in the Sugnugur sub-catchment focusing on hydro-meteorological behaviour along an altitudinal gradient (Fig. 4). During field campaigns in 2011 and 2012, soil temperature, soil moisture, meteorological parameters as well as the structure of the coniferous forests were monitored at various sites in the upper Sugnugur valley. The sites were selected according to a forest health survey in which they were classified into three categories: 1) undisturbed / vital, 2) harmed through forest fire, 3) exclusively dead trees. In addition, unforested sites in the vicinity of the forest plots were selected for soil water and temperature monitoring. Results show that the unforested sites are free of permafrost since they are mostly on southern exposed slopes with high radiation intensities. Consequently, soil temperatures are comparatively high while soil infiltration rates and soil moisture are low. Runoff mainly occurs as fast surface flow during high-intensity precipitation events. Further, there are clear differences between the three forest categories. Under vital forest the active layer appears to be surprisingly shallow (i.e., permafrost is close to the soil surface), soil infiltration rates as well as the water retention potential are comparatively high. Delayed matrix flow in the well-developed organic layer and in the mineral horizon dominates. Besides, the depth of the active layer seems to increase with decreasing forest vitality, accompanied by warmer soil temperatures while soil moisture tends to decline. Runoff generation is influenced by a relocation of flow paths. Pipeflow occurs between the dead organic cover and the mineral horizon as well as along an effective network of deep flow paths which probably originate from root canals. Thus, the investigations support the hypothesis that forest disappearance alters water retention in the headwaters and thus water availability in the dry steppe zone. Climate change probably supports this process through additional warming and a decrease of snow cover which again reduces available soil water. The collected environmental data and the improved process understanding will finally lead to improved hydrological modelling of the entire Kharaa basin.

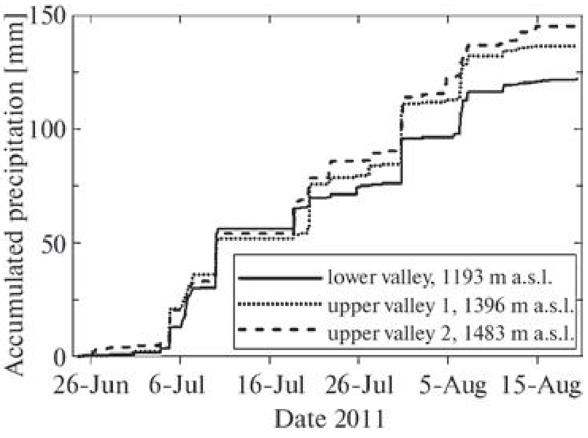

Fig. 4. Altitudinal precipitation gradient in the Sugnugur valley.

WATER QUALITY AND ITS DETERMINANTS

The Selenga River Basin is, by international standards, characterized by a relatively low population density of around 5 people/km^2. However, localized concentrations of population, an often poor state of urban waste water infrastructures, high livestock densities in the riverine floodplains and large-scale mining activities are potential threats to the aquatic ecosystems of the Selenga, its tributaries and Lake Baikal. In the recent past, water quality monitoring in the Mongolian and Russian parts of the river basin was not harmonized, which is maybe best reflected by the fact that the two countries are located in the upstream and downstream sections of the river system, and thus faced different water resources problems. This followed by discrepancies in water policy objectives and understanding of monitoring purposes.

Industry and Mining-Related Pollution in the Selenga River Basin

A state inventory for surface water in Mongolia conducted in 2003 showed that even though most rivers in the country were in relatively pristine condition, at least 23 rivers in 8 provinces were morphologically changed and/or polluted due to mining activities [Batsukh, 2008], including the Selenga and several of its tributaries. Chemical analyses of water and sediment samples taken in the Selenga River Basin showed a relative enrichment in comparison to natural background conditions (detected for suspended and bottom sediments) and maximal permissible concentrations (detected for dissolved load) with several elements, including As, Cd, Mn, Pb and Zn (Table 3).

Most of As and Zn are transported as dissolved load, whereas Cd, Mn and Pb are almost completely adsorbed by suspended solids. One source of the relatively high concentrations of As appears to be the lignite deposits in Northern Mongolia. The industrial centers of Erdenet (Mongolia) and Zakamensk (Russia) are important sources of heavy metal pollution. Mercury, which is regarded as a serious threat to water resources near mining operations in the area [Batsukh, et al. 2008], never exceeded maximum permissible concentrations in suspended sediments. However, due to historical use of mercury for gold extraction, high concentrations were found in bottom sediments near major mining operations in the Dzida river in Russia (up to 1,6 times) and Kharaa river basin (up to 20 times in Borroo river) in Mongolia.

Anthropogenic Nutrient Enrichment in the Kharaa River Basin

In recent years human activities have lead to increasing concentrations of phosphorus and nitrogen in the Kharaa River. In order to monitor this trend, we have used surveillance data provided by Mongolian authorities for two monitoring sites (upstream and downstream of the city of Darkhan) and complemented this monthly to bi-monthly dataset with additional monitoring from 2006 to 2012 to observe gradients of nutrient concentrations along the main river course and its tributaries, extending from the headwaters in the Khentii Mountains to the outlet of the river basin at Buren Tolgoi. This multi-year sampling survey has been carried out along the Kharaa River in spring, summer and autumn each year in order to investigate seasonal variations but also to create a time series of quality assured data. Nutrients were determined after filtration by photometry and standard cuvette tests (Hach-Lange Inc.) with standard solutions as blind tests. The systematic evaluation of the nutrient species for phosphorus (total phosphorus, soluble reactive phosphorus) and nitrogen (nitrate, nitrite, ammonium, total nitrogen) provides a comprehensive picture of recent nutrient trends. For the evaluation of results and determination of water quality classes we used the Mongolian surface water classification 143/a/352 [MNE & MH, 1997], the Mongolian drinking water standard MNS 900: 2005 [MNCS&M, 2005] and WHO guidelines as comparisons. The latter two references are relevant since river water is frequently used for drinking and food preparation in rural areas.

The evaluation of concentrations based on Mongolian Surface Water Guidelines resulted in a ‘very good’ to ‘good’ chemical

Table 3. Heavy metal loads of water and sediments in the Selenga River System

River	Period	Sample	As	Cd	Mn	Pb	Zn
MPC			**0,05**	**0,005**	**0,01**	**0,006**	**0,01**
C_{ucc}			**2**	**0,102**	**527**	**17**	**52**
Selenga delta	2011, August	DL	1,5	0,01	51	6,9	44
		SL	16.6	1.81	1483.7	219.6	534.1
		BS	7.2	0.25	635	19	95
	2012, June	DL	0.4	0.027	32	2	9.2
		SL	12.71	0.34	1237.11	29.21	85.91
		BS	2.7	0.17	472.54	19	48
Selenga, Russian-Mongolia border	2011, August	DL	2.1	0.01	41	0.64	53
		SL	22.8	0.42	2155.7	38.3	125.7
		BS	3.1	0.19	581	14	45
	2012, June	DL	–	–	–	–	–
		SL	–	–	–	–	–
		BS	3.6	0.2	666.20	18	59
Djida River, below Modonkul mining	2011, August	DL	0.25	1.1	93	0.26	180
		SL	10.0	10.82	1803.3	704.9	1639.3
		BS	9.6	9.7	1859	500	730
	2012, June	DL	0.4	0.077	6.2	0.36	20
		SL	8.33	2.13	3033.33	40.00	156.67
		BS	3.9	0.37	526.76	36	81
Orkon river downstream	2011, August	DL	5.3	0.005	0.15	0.05	0.5
		SL	11.5	0.23	1113.0	29.6	80.0
		BS	4.5	0.22	519	14	59
	2012, June	DL	2.9	0.02	34	0.45	1.5
		SL	12.20	0.09	1890.24	17.07	67.07
		BS	5	0.15	565.49	15	45
Tuul river below Ulaanbaatar	2011, August	DL	6.7	0.005	0.15	0.05	0.5
		SL	2.6	0.05	289.0	6.4	17.3
		BS	6.6	0.24	643	16	66
	2012, June	DL	6.7	0.005	0.15	0.05	0.5
		SL	2.6	0.05	289.0	6.4	17.3
		BS	6,6	0,24	643	16	66
Kharaa river at outlet (Buren Tolgoi)	2010, May	SL	12.9	0.59	1305.0	22.8	136.3
	2010, September	SL	13.38	0.53	1404.0	18.3	124.8

DL = dissolved load (mg/l), SL = suspended load (mg/kg), BS = bottom sediments (mg/kg)
MPC – maximal permissible concentrations according to Russian laws (mg/l)
C_{ucc} – lithosphere averages (mg/kg; according to Wedepohl, 1995)
DL should be compared to MPC; BS and SL should be compared to C_{ucc}

status for nutrients in the headwaters. However, in the mid- and more significantly in the downstream sections of the Kharaa River concentrations of total phosphorus and total nitrogen lead to a 'moderate' or 'poor' status according to the above cited guidelines. The loads of orthophosphate-P at the basin outlet (Buren Tolgoi gauge) show a constant increase during the observation period (Fig. 5).

The remarkable increase from 33 to 57 t/yr orthophosphate-P is an indication for the increasing nutrient release into Kharaa River by diffuse sources, mainly urban areas without connection to treatment plants. For total nitrogen concentrations and loads a similar trend could be observed [Hofmann et al., 2013]. As a result of nutrient emission modelling with the MONERIS model, urban settlements are the main sources for nitrogen and phosphorus emissions contributing about 55% (nitrogen) and 52% (phosphorus) of the total emissions [Hofmann et al., 2011]. The proportion of point sources (WWTP) was much higher for nitrogen (30% of total N emissions) than for phosphorus (15% of total Permissions). Since only 35% of the total population in the river basin are connected to WWTPs, unconnected urban areas represent an important proportion of the total emissions (38% of phosphorus and 25% of nitrogen emissions).With regard to phosphorus, river bank erosion is another significant source of nutrient release [Hartwig et al., 2012; Theuring et al., 2013]. This process is triggered by an increasing degradation of riparian vegetation due to high livestock densities with free access to the running waters. The rising nutrient levels have a significant eutrophication potential in the Kharaa River and functional shifts of the macroinvertebrates and fish fauna have been observed already [Hofmann et al., 2011]. These upstream trends also help to explain the nutrient enrichment further downstream in the Selenga's main stem. While for the 1970s, phosphorus concentrations between 2 and 13 µg/l were reported, recent levels are between 5 and 19 µg/l [Sorokovikova et al., 2013].

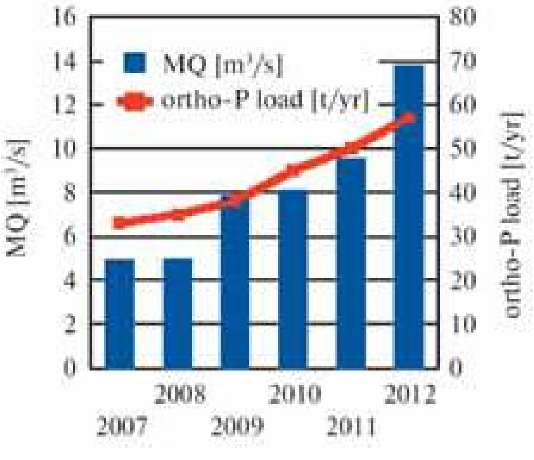

Fig. 5. Observed discharge and orthophosphate-P loads at the outlet of KRB (2007 to 2012).

Identification of Fine Sediment Sources and Impacts of their Influx

Recent studies on the main drivers and sources of fine sediment input in the Khaara River catchment using isotope based sediment source fingerprinting techniques [Hartwig et al., 2012, Theuring et al., 2013] identified riverbank erosion (74,5%) and surface upland erosion (21,7%) as the main contributors to the suspended fine sediment load (grain size < 10 µm) in the catchment. Although agricultural areas in middle and lower parts of the KRB are prone to surface erosion due to temporary vegetation cover and fallow periods, low precipitation, gentle slopes and wide floodplains in the valley bottom mean that surface-eroded sediments rarely reach the river system. By contrast, riverbank erosion is a significant process (Fig. 6) at the catchment scale. Although naturally high in a unregulated, meandering lowland river, a lack of riparian vegetation caused by high grazing intensities strongly enhances riverbank erosion. In fact, only 20 to 35% of the riverbanks in the lower catchment still have near-natural vegetation. In the pristine upstream areas of the catchment, which are usually forested, surface erosion is a more prominent contributor (36,2%) to the total load. Even though riparian vegetation is still intact in these regions,

Fig. 6. Riverbank erosion on the Kharaa.

63,8% of the suspended sediments stem from riverbank erosion.

Sediment budget calculations using the SedNet model and the revised universal soil loss equation (RUSLE) estimate an annual flow of 16,2 kt of suspended sediments at the catchment outlet, comparing well with measured data (mean: 20,3 kt/a) [Theuring et al., 2013]. However, as shown before, surface erosion estimates are only of limited use to investigate fine sediment input in river systems in this region, due to the dominance of riverbank erosion. These findings, which are characteristic for catchments in semiarid steppe regions, have important implications for the understanding of fine sediment generation in the Selenga-Baikal river basin. In terms of management options, they shift the focus of erosion prevention measures from agriculture to animal husbandry as a key determinant of sediment influxes.

Besides acting as an agent for heavy metal pollution input from the terrestrial environment into the river system, increased suspended fine sediment loads also affect the aquatic ecosystem e.g. in terms of physical riverbed clogging. The fine sediments either remain suspended or infiltrate into the interstices of the riverbed, causing severe effects on functions of the surface and subsurface water compartments like primary production, hydrological connectivity, biogeochemical turnover and habitat. Therefore, an intensive monitoring program was conducted on the micro-scale spanning from relatively pristine (river kilometer 79) to heavily stressed reaches (river kilometer 120 and 128, see Fig. 7) of the Kharaa River [Hartwig et al., 2012]. The measurements included parameters on the hydromorphology, hydrology, water quality and biology of both the surface and subsurface water compartments. It was shown that especially the sediment input of the tributary draining the second largest and

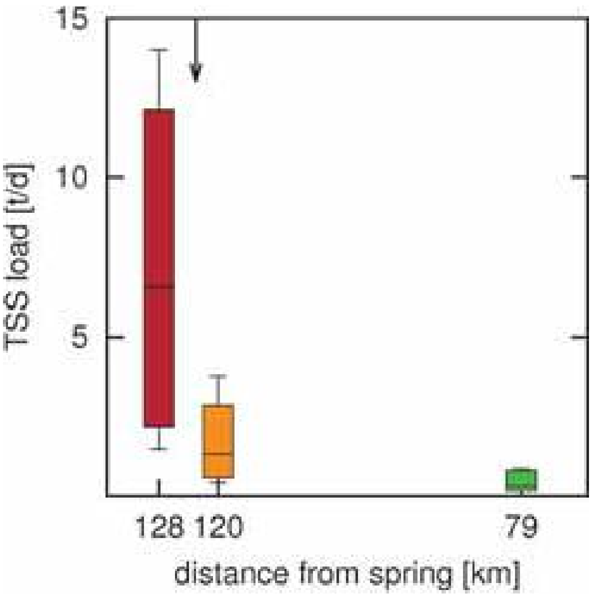

Fig. 7. Total suspended sediment loads in the Kharaa during medium flow (arrow indicates confluence of Zagdelin Gol).

intensively used sub-catchment of Zagdelin Gol affected almost all considered functions. The algae succession and whole stream productivity was decreased compared to the reach upstream the confluence. Through a high fine particulate fraction in the uppermost sediment layer the vertical connectivity declined. Thus, the penetration depth of surface water rich in oxygen and organic carbon into the riverbed decreased, lowering the potential for biogeochemical metabolism by means of depth. However, the higher fine sediment fraction may have provided more surface area for microbes as oxygen respiration rates were found to be in the same range as upstream the confluence. Habitat quantity and quality for higher organisms was concluded to be affected as well. As the assessment of the macroinvertebrate community revealed [Hofmann et al., 2011], this degradation is permanent as indicated by a shift in the functional composition of the community. This leads to the conclusion that either the high discharge events were not strong enough to break off the clogging layer or that the suspended sediment input was high and long-lasting. Although the sediment load during mid-flow events at the more pristine region was low, an increased fraction of fine sediment was observed in the deeper riverbed sediment. The big sediment pore space and high vertical downward flow velocities found here may have increased the intake of suspended material during flood events. Due to this susceptibility for an inner clogging, fine sediment input needs to be controlled in order to protect the aquatic ecosystem.

CONCLUSIONS

Water management in the Selenga-Baikal Basin, which is of global importance as a freshwater reservoir and unique ecosystem, faces several challenges. The Selenga and its tributaries do not only constitute a transboundary river basin with a lack of harmonized monitoring; the large size, low population densities and challenges related to the political and economic transformation also result in a scarcity of environmental data. In such a situation, a comprehensive monitoring of water-resources is almost prohibitive. Therefore, one promising approach is to combine intensive monitoring in a representative model region with a more synoptic monitoring in the larger basin. This strategy seems plausible for the basins of the Kharaa and Selenga rivers which are comparable with regard to the (bio-)physical and socio-economic environment [Karthe et al., 2013].

This paper integrated findings of research activities focusing on the micro (local), meso (Kharaa) and macro (Selenga-Baikal) scale. With regard to water availability, the most relevant drivers include climate and land use changes. In contrast to a long-term (20th century) trend of increasing water availability, the period from 1995 onwards was unusually dry for the entire Selenga River Basin. For the future, a predicted increase in precipitation may outweigh the effects of rising temperatures and evapotranspiration. However, land use changes appear to be equally important. While remote sensing data can help to survey such changes over large areas, only field investigations at the site scale can help to understand the impacts of land cover changes on hydrologically relevant processes (such as infiltration, surface runoff, evapotranspiration or water storage) in detail. Observations in the Sugnugur valley, a relatively pristine headwater region in the Kharaa River Basin, indicate that the loss of forest cover (due to logging, land clearance and wildfires) in one sub-region is a major threat to water availability even at river basin scale.

With regard to water quality, important stressors include fine sediment influxes, pollution of water and sediments with heavy metals, and –at moderate but increasing levels- nutrient inputs. In particular for the Mongolian part of the Selenga River Basin, high livestock densities in the riverine floodplains are an important cause of degrading vegetation and consequently riverbank erosion. The release of toxic substances into surface water bodies and their accumulation in sediments can frequently be related to mining activities. With regard to nutrient loads, population growth in urban areas and the poor state of wastewater treatment plants are of concern. Even though most of the surface water bodies cannot be considered eutrophic, there is a clear trend of rising nutrient levels.

From a management perspective, the integration of findings from the Selenga River Basin shows that present and future problems appear to be comparable in (sub)basins of different scales. Therefore, an effective monitoring concept for the macroscale Selenga-Baikal Basin could consist of an intensive monitoring in a selected model region (such as the Kharaa River Basin) and synoptic surveys at the large scale. At the same time, solutions that have been proven effective in this model region have a high potential for successful duplication in comparable locations in the Selenga-Baikal Basin.

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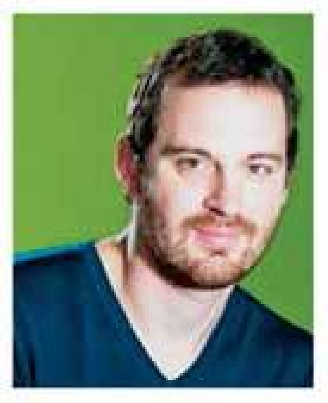

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