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WATER RESOURCES ASSESSMENT OF THE SELENGA-BAIKAL RIVER SYSTEM

SERGEY CHALOV, NIKOLAY KASIMOV, MIKHAIL LYCHAGIN, EKATERINA BELOZEROVA, GALINA SHINKAREVA, PHILIPP THEURING, ANNA ROMANCHENKO, NIKOLAY ALEXEEVSKY, ENDON GARMAEV

SUMMARY

Paper provides basin-scale integrated assessment of water resources of the largest tributary of Lake Baikal (the Selenga River) extending from northern Mongolia into southern Siberia in Russia with special emphasis on total flow of water through a basin, its quality, structures, laws and economic factors that control its use for the present and future. The water quality and flow data were obtained from historical measurement campaigns, long-term national monitoring, and a novel field campaign done in 2011-2012. The results provide evidence on a very low water availability in upper parts of the basin and insufficient water quality exhibiting high concentrations of dissolved and suspended heavy metals in downstream parts of the Selenga River where elevated concentrations of dissolved and suspended forms of Mn, Fe, Cu, Mo are observed with local 10-20-fold increases of maximum permissible concentrations MPC below large industrial and mining centers. The main pressure on water resources is reported for some Mongolian (Tuul below Ulanbaatar and Zaamar goldfield and the Khangal River below copper-molybdenum mine-mill complex Erdenet) and Russian rivers (Modonkul-Dzhida River system below Zakamensk wolfram-molybdenum mining and processing factory). We concluded that future water resources will depend on general socio-economic trends in both Mongolia and Russia with special focus on development of mining concessions which overlap with current or planned hydropower projects and population changes and thus water consumption in the region. Political and economic dialogue between two transboundary countries will determine status of water resources in the near future. We argue that water conservation in the Selenga River Basin should benefit from introduction of market-based mechanisms in water policy.

Keywords: Selenga, water availability, water quality, transboundary river

1. INTRODUCTION

The inhabitants of Central Asia are fairly well provided with water – on average, about 4000 m3 of surface (river) water per person annually (Shiklomanov & Rodda 2003). At the same time water resources assessment has become a high priority in the Central Asia, in large part because competition for water is becoming more intense. Water resources are inevitably decreasing, yet the population of the region is predicted to grow by an estimated 40% by 2025 (Valentini et al. 2004). The main problems of water resources availability are connected with pollution.

Central Asian region is characterized by high amount of transboundary rivers resulting in even higher probability of water-related conflicts. When rivers cross the boundaries, conflicts can occur over a particular state's right to use and divert waters, potentially at the expense of other riparian states. Many problems are associated with an impact on water quality which can cause negative effects on water resources in adjacent countries. Gathering reliable information on transboundary river water resources remains a crucial task for international water management and environmental pollution control. Countries located in the lower parts of the river basins depend on water use and management strategies in adjacent upstream countries.

The Selenga River, which originates in Mongolia, contributes about 50 % of the total inflow into Lake Baikal. Together with the Angara and Enisey Rivers it forms the longest river network in Eurasia. The Selenga River Basin comprises an area of 447,000 km2. The Selenga basin is located nearly at the heart of the Asian mainland and is characterized largely by mountain topography. Within Mongolia, it includes the southern spurs of the Sayan mountains (in the area of Lake Hovsgol), the northern slopes of Khangai Range, the western part of Khentei Range. Within Russia, most of the basin is occupied by the Selenginskoye upland, the mountain ranges of the Khamar-Daban system in the west as well as the mountain ranges of the Khentei-Chikoi table-land, Yablonevui Range – in the east.

Upper part of the basin (totally 67 %) is located in Mongolia which is currently experiencing rapid socio-economic development. Mining, industrial and agricultural activities as far as increasing water consumption within the Selenga drainage basin affect water resources availability and quality along the river and its tributaries. In the upper part of the basin water scarcity is the main problem of water resources due to the fact that potential evapotranspiration exceeds the annual precipitation by a factor of almost 3 (Karthe et al. this issue). For the whole river basin, the confidence intervals for the basin-average values of precipitation and runoff are 291-351 and 62-72 mm respectively; and 219-289 for evaporation (Sinyukovich 2008). Maximum river discharge is driven by the spring melt of the accumulated snowpack. A second peak in river hydrographs is observed in late summer, August or September, during the rainy season.

Extensive research has been conducted on the river runoff (Semenov & Myagmarjav 1977, Sinyukovich 2008, Garmaev & Khristoforov 2010), water quality of Lake Baikal and the

Selenga River (Munguntsetseg 1984, Anikanova et al. 1991, Garmaev 2010, Korytny et al. 2003, Khazheeva et al. 2004, Chebykhin et.al 2012), including sediment transfer (Boyle et al. 1998, Batimaa 2000, Khazheeva et al. 2004, Potemkina 2011, Chalov et al. 2012, Thorslund et al. 2012). Less studies have been devoted to the integral assessment of water resources in the transboundary river basin (Garmaev & Khristoforov 2010) and were mostly focused on it either Mongolian (Kuznetsov 1955, Davaa 2007, Karthe et al. this issue) or Russian part (Korytny 1990, Molotov et al. 1999, Plusnin & Gunin 2001).

Limited information is available on basin-scale integrated assessment of water resources which combine both total flow of water through a basin, its quality, and the structures, laws, regulations, and economic factors that control its use for the present and future. The main hypothesis of the present paper is that integrated water resources assessment of the Selenga River includes water availability and water quality. Paper is addressed to the full review of the recent estimates in this subject and provides new data from field-based basin-scale monitoring. We started from from detailed investigation of water availability and quality, estimates of the local pollution sources and future trends in water resources use (with a focus on building of reservoires and water transfer projects), ending with an investigation of the legal framework for water resources managment and monitoring. The work more specifically aims at quantifying renewable water resources along the Selenga River, water resources per capita availability and downstream impacts of hot spots on water quality. Through combining available hydrological information from national network of around 60 stream gauging station sites across the basin in 2 countries and our field works in 2011-2012, we go further into understanding of future status of water resources in the area. The latter is essential to the knowledge needed for more detailed impact assessments and management decisions, regarding remediation planning and measures.

2. METHODS AND MATERIALS

Many of water use problems on transboundary river systems arise from lack of reliable information about quantity and quality of renewable water resources. Present paper contains results of water resources assessment which is based on information from national gauging network in Selenga basin and environmental survey done by Lomonosov Moscow State University in 2011 and 2012. Water flow and levels in streams were obtained from 62 flow measurement stations with observation period till 2011. Water quality assessment was done on the base of environmental survey in 2011 and 2012 (Chalov et al. 2012, Thorslund et al. 2012) with some additions from national hydrochemical monitoring. The results were synthesized with review of laws, regulations, and economic factors that will control water resources use in future (Plusnin & Gunin 2001, Simonov, 2013).

2.1 DATA FROM NATIONAL GAUGING NETWORK

The first routine measurements of river flow in the Selenga River Basin began on the 1930. The number of gauging stations reached the maximum in 1970. After 1970s the number of gauging stations has declined and in 2003 there were only 57 national gauges. Today there are 62 flow measurement stations, 44 belong to Russian part of Selenga basin, 18 – Mongolian part (Tab.1, fig.1). The density of gauging stations in Russia is one station on 3750 km^2 and in Mongolia is almost four times less (1 station in 16,500 km^2). Duration of the stream flow monitoring at the gauging stations in Selenga basin varies significantly (Tab.1). Annual water runoff W (m^3/year) was calculated from average water discharge Q_0 (m^3/sec)

[1] $$W = Q_0 T$$

where T = 31.5·106 seconds (per 1 year). Water resources per capita (WR) availability was calculated as the value of annual rainfall (Pr) divided by the total population (m3/capita/year) (Nagarjan 2009) and was used to indicate the degree of water shortage or scarcity. In order to avoid influence of high evaporation rates on the WR estimates, we compared the results with the value of annual runoff (W) divided by the total population (m3/capita/year). Countries with less than 1700 m3/capita/year are regarded as countries with "existing stress", while countries with less than 1000 m3/capita/year are regarded as having "scarcity". Precipitation and discharge data were taken from national hydrological monitoring for Selenga basin (Sinukovich 2008).

Tab.1: *Number of gauging stations in the Selenga River Basin over time*

Year	Number of gauging stations		Total number
	Within Mongolia	Within Russia (USSR)	
1907	–	5	5
1915	–	2	2
1930	–	16	16
1940	–	33	33
1950	5	50	55
1960	11	70	81
1970	26	60	86
2003	18	39	57
2009	no data	44	no data

Routine observations of sediment load have been done at relatively dense gauging station network. In Mongolia sediment load data was episodically obtained at 6 gages that have been in use only occasionally. Previous water quality surveys (Stubblefield et al. 2005) were focused on Selenga, Orkhon, Tuul, Yeroo, Kharaa and Eg Rivers in 2003. Few studies have addressed matter movement in small catchments (Dallas 1999, Onda et al. 2007). In Russia there are 12 gauging stations for measuring the sediment load at 4 rivers (Fig.1). As far as significant increase of sediments delivery into rivers have been reported recently due to anthropogenic reason and mostly mining activities (Chalov et al. 2012), suspended sediment concentration SSC (mg/l) may influence water quality and water resources assessment.

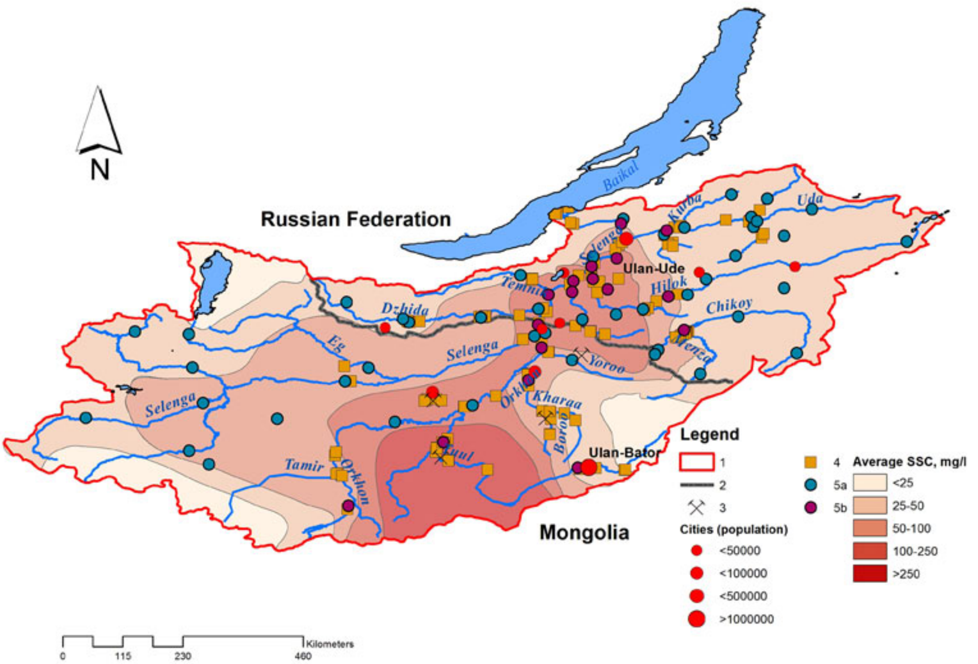

Fig.1: *Selenga River network, location of monitoring stations and catchment zoning by annual SSC. 1 – Selenga basin watershed; 2 – Russian-Mongolian border; 3 – mining areas; 4 - Sampling points during 2011-2012 field campaigns; 5a – Gauging network; 5b – Gauging stations with sediment load measuring. Annual SSC is given according to (Semenov & Myagmarjav 1977)*

Basic hydro-chemical monitoring of Mongolian waters began as early as the late 1940s, but measurements for nutrients and selected pollutants only began around 1980 (Kelderman & Batimaa 2006). Within the Mongolia surface water quality network there have been 72 monitoring stations, nine of which are located in the Tuul and Orkhon River basins. Long-term abundant research has been performed by IWRM MoMo project in the Kharaa River

Basin (IWRM-MOMO www.iwrm-momo.de) which include study on material flow and mass balances within inter- and transdisciplinary approach of the project. Routine observations of water quality in Russia began in the 1940.

2.2 ENVIRONMENTAL SURVEY

The data obtained from national gauging network is rather limited for predictions of water resources shifts due to climatic and anthropogenic changes. Both scarcity of stations, insufficient program of observations as far as lack of data exchange between countries constrain full description of water quality along river system. The central objective of our field campaigns was to conduct a broad water flow and water quality assessment in various scales. The field-based water resources assessment program included measurements in the Selenga River (Mongolia and Russia) in 2011-2012 to understand current water discharges and water quality, quality of streambed sediments and suspended sediments, suspended and dissolved loads of the transboundary river system. Surveys of water flow and water quality were conducted at 110 field stations during July-August 2011 and June 2012. Documented field monitoring stations in Mongolia are located at the Tuul River, the Orkhon River, the Eg River, the Yeroo River the Khangal River, the Selenga River and the Kharaa River. In Russia the observation stations were located at the main stem of the Selenga River and its main tributaries – Dzhida, Temnik, Chikoy, Hilok, Orongoy, Uda, Itantsa, Kiran, Kudara, Zheltura, Udunga, Suhara, Tugnui, Menza, Buy, Bryanka, Ilka, Chelutay, Kurba, Kodun, Kizhinga, Ona. Additional information was obtained from recent field campaigns which were focused on the environmental surveys of some parts of the Selenga River Basin (Stubblefield et al. 2005, AATA 2008, Baljinnyam et al. 2009, JangMin et al. 2010, MCA 2011).

In our environmental surveys in-stream measurements were made for turbidity (T) by HACH-2100P and water discharges by the Acoustic Doppler Profiler (ADP) from bridges. Depth-integrated water samples were collected with a GR-16M bottle sampler at the midstream. Samples were filtered through pre-weighed membrane filters with the "Millipore" filtration system. The filters were then oven-dried and re-weighed. The linear regression between T and SSC was obtained

[2] $$SSC = aT + \mathbf{b},$$

where a and b are regional coefficients which are related to the sediment grain size and particulate organic matter. For the Tuul, Orkhon and Selenga Rivers the slopes a are respectively equal to 0.58, 1.05, 1.17, the coefficients b equals to 30.0, 20.5, 4.89 (the significance of the correlation coefficients are 0.88, 0.99, 0.86).

For other water and sediment quality parameters, a grab water, suspended matter and streambed sediments samples were obtained and returned to the laboratory for analysis. Total amount of material included 120 samples of water and suspended matter 140 streambed sediments. All samples were analyzed for 62 elements by inductively-coupled plasma mass spectrometry (ICPMS) using the semi-quantitative mode and 10-fold automated dilution during the analysis. Grain size analysis of suspended sediments was conducted with the Laser granulometer Fritsch Analysette 22.

The statistical analysis of the geochemical data included the average content of elements, standard deviations, coefficient of variation and correlation coefficients between water and sediment quality parameters. The chemical composition was compared with the world averages and national MPC values for water bodies of drinking and fishery (GN 2.1.5.1315 03). To determine the regional geochemical specialization the content of trace elements in sediments was compared with the lithosphere averages (Vinogradov 1962, Wedepohl 1995). Concentration Factor (CF_{ucc}) was calculated as

[3] $$CF_{ucc} = C/C_{ucc},$$

where C is concentration of specific element, and C_{ucc} – concentration of the same element in upper continental crust (Wedepohl 1995). Only elements which are characterized by elevated concentrations (so-called main pollutants) are considered in the present paper.

3. PRESENT STATUS OF WATER RESOURCES IN SELENGA BASIN

3.1 WATER RESOURCES AVAILABILITY

According to the downstream gauging station Raz'ezd Mostovoy (Buryatia), the mean annual runoff of the Selenga River is 28.7 km^3, the maximal runoff is 46.4 km^3, the minimal is 16.3 km^3. The mean annual water discharge of Selenga at the Raz'ezd Mostovoy station is 923 m^3/s. The largest water discharge was observed at the 11th of June 1936 (7620 m^3/s), the minimal summer water discharge was fixed 6th – 7th of July 1969 (518 m^3/s), the minimal winter discharge was marked at the 11th of February 1936 (30.6 m^3/s). At the Russian-Mongolian State border the mean annual water discharge is 306 m^3/s and the annual runoff is 9.68 km^3 (Fig.2).

The specific water discharge decreases along rivers of Selenga basin due to vertical zonality. Interannual variations of the Selenga basin renewable water resources are significant. For the most high-water years the mean annual flow is 2-3 times higher in comparison with low-water periods for the Selenga River and its left tributaries (Muren, Eg, Dzhida, Temnik), and 4-5 times higher for right tributaries (Orkhon, Tuul, Chikoy, Khilok, Uda) (Semenov & Myagmarjav 1977). Variation coefficient varies from 0.20 to 0.50. At the present time low-water period (1996-2011) is observed and usually is explained (Berezhnyh et al. 2012) by rainfall decreases during July and August which is caused by reduce in circulation at the air masses convergence of midlatitudes and East Asian cyclone.

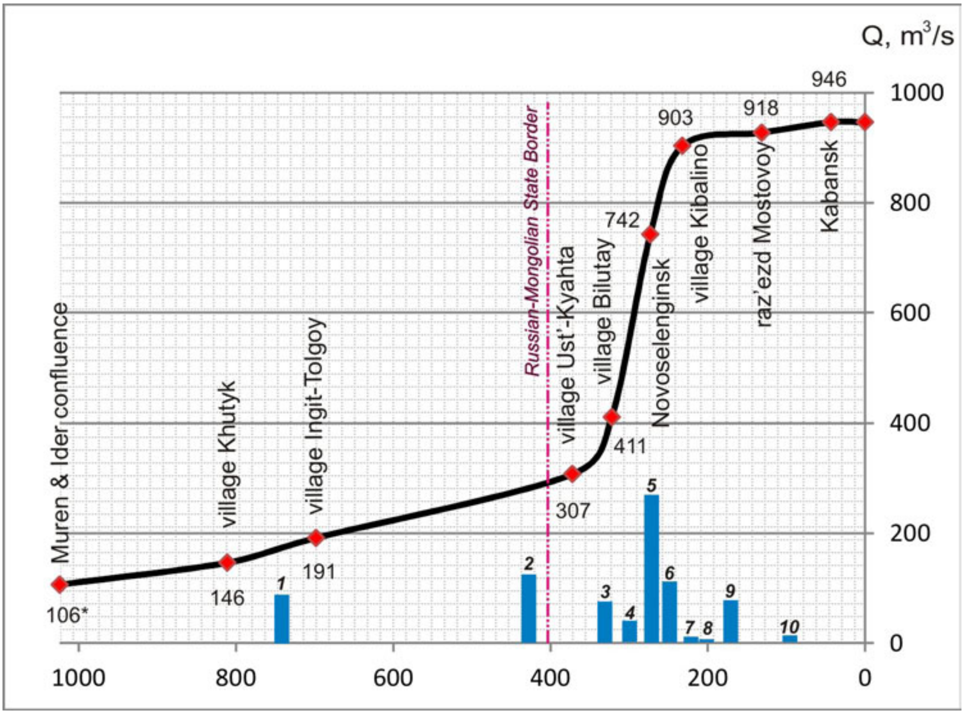

Fig.2: *Longitudinal changes of renewable water resources along the Selenga River. The tributary mouths: 1 – Egiyn-Gol, 2 – Orkhon, 3 – Dzhida, 4 – Temnik, 5 – Chikoy, 6 – Khilok, 7 – Orongoy, 8 – Kuytunka, 9 – Uda, 10 – Itantsa. * − initial assessment*

** data from national state monitoring Roshydromet*

Annual water flow is unevenly distributed during the year: 80-90 % of flow occurs during warm season, whereas during winter time it is minor or non-existent. Rivers freezing happens during cold period. Almost every year water flow intermits at rivers with a catchment area up to 5000 km². Occasional freezing occur at the larger rivers (catchment areas of 40,000 km²).

The river basin is characterized by very high spatial variability of water resources availability and demand. The Russian part of the catchment is populated by 0.939 mn inhabitants, including almost 0.78 mn people in Buryatia. With relatively small population density (2.1 inhabitants/km2) and average 28.7 km3/year of water resources, Russian part of the basin is among the most secured areas in Central Asia by water (Tab.2).

Mongolia is regarded to be World's most sparsely populated country with average population density 1.7 inhabitants/km2. Nevertheless in some parts of the Selenga River Basin population density is very high. Over 60 % of the Mongolia total population and more than 30 % of the livestock, nearly 90 % of the agricultural areas are located in Orkhon river basin, which include Mongolia capital Ulanbaatar with over 1.2 mn population. In the upper part of the basin some rivers already experience drastic lack of water. The availability of water is classified as very low according to international standards (Nagarajan 2009) in both variants of WR per capita calculations (via annual rainfall or runoff). The most negative situation is observed for the Tuul River which upstream part (up to Ulanbaatar) is considered to be "water stressed". Water availability here is 969 m3/capita/year. Minimal river water flow may be experienced during spring season along the southern outskirts of Ulanbaatar and at times there may be no actual river discharge, but only waste water flow for as much as 30 km downstream (Javzan et al. 2010).

Tab.2: *Availability of water resources within Selenga basin*

Area	Population	Area km^2	WR amount km^3/year	Precipitation mm	WR per capita availability m^3/capita/year[1]	WR per capita availability m^3/capita/year[2]
Tuul upstream (Ulaanbaator)	1,300,000	6300	0.76	200	582	969
Orkhon basin	1,490,000	132,000	3.60	242	2,413	21,439
Mongolia	1,500,000	299,000	9.68	248	6,454	49,435
Russia	939,100	447,000	28.7	321	30,561	50,589

[1] *- annual runoff divided by the total population*

[2] *- annual rainfall divided by the total population*

3.2 WATER RESOURCES QUALITY

Water resources quality depend on contaminants delivery to rivers which could be transported downstream as suspended and dissolved load. Map of average suspended sediment concentration (Semenov & Myagmarjav 1977) shows that the sediment concentrations is greater (100–250 g/m3 and > 250 g/m3) in the midstream and downstream area of the Orkhon and Tuul River sand on the downstream of Selenga and her tributaries in Russian part of basin (Fig. 1). The lowest loads (<50 g/m3) appear in the upstream of Orkhon and Selenga, eastern part of Selenga's downstream. The primary chemical composition of water of the Selenga River and most of its tributaries follows the pattern of $Ca^{2+} > (Na^{+} + K^{+}) > Mg^{2+}$, and $HCO_3^{-} >> SO_4^{2-} > Cl^{-}$. Aquatic systems of the Selenga basin in general are characterized by low salinity, slightly alkaline pH, and calcium bicarbonate composition of the water.

In the Mongolian part of the basin, waters of the Orkhon River, downstream Tuul and the Yeroo River were recently reported to get impacted (JangMin 2010). Orkhon, Tuul, Kharaa and Khangal are experiencing increased pollution by urbanization and industrial activities within the basin (MNE 2007, Batimaa et al. 2011). In Russian part the most serious impact is recently reported at Modonkul-Dzhida River system and below Ulan-Ude in the lower part of the Selenga River (Tulokhonov et al. 2009).

Mining, industrial and agricultural activities within Mongolian part of Selenga drainage basin recently lead to the increase in sediment delivery into rivers (Chalov et al. 2012, Thorslund et al. 2012). Only occasional grab measurements characterize alterations of SSC within Mongolian part of the basin. At the Selenga midstream above the Eg River SSC varied in 1934 between 1.2 mg/l (20th February) to 1193 mg/l (8th August) (Kuznetsov 1955), whereas in 2001 it was 11.5 mg/l (18th-24th August).During our field campaigns SSC varied from 9.51 mg/l (16th June, 2012) to 114 mg/l (2nd August, 2011). At the confluence of Orkhon and Tuul 65-fold increase of SSC was observed during summer floods for the Tuul River (from 11 mg/l at the 19th October, 1934 to 716 mg/l at the 26th August, 1934) and 43-fold for the Orkhon River (from 23.3 mg/l at the 17th June, 2012 to 1000 at the 7th May, 1934). At Yeroo downstream SSC changed from 7 mg/l (7th-11th August, 2001) (Stubblefield et.al 2005) to 658 mg/l (1st July, 1934) (Kuznetsov 1955).

At the low part of the basin within republic of Buryatia of Russian Federation due to economic recession of the last decades and decrease of land use sediment delivery and sediment transport was reported to decrease (Potemkina 2011). At Selenga downstream (Raz'ezd Mostovoy gauge) the mean SSC annual decreased from 79 mg/l (Semenov & Myagmarjav 1977) to 39.3 mg/l since 1983 to 2008.

During 2011 survey SSC varied between 1.43 mg/l (the Dzhida River at the mouth) to 2850 mg/l (Orkhon at Kharokhorin). The average SSC values in Mongolian part of the basin (270 mg/l) were in 15 times higher than in Russia (19.0 mg/l). Within Russian territory the maximal SSC was observed at the Selenga delta (70.5 mg/l) and the rest of SSC values were less than 50 mg/l. While in Mongolia, nearly 70% of the values were more than 50 mg/l, in 43% of cases – more than 100 mg/l.

For the 2012 the average SSC was 127 mg/l, the minimal – 1.68 mg/l (Tuul, upstream from Ulaanbaator) and the maximal – 1249 mg/l (Tuul, downstream from Zaamar). For Russian part of Selenga basin the average SSC value was in 2 times less (63.6 mg/l). The lowest value in Russia was observed at the same site that in previous year – the Dzhida River (1.74 mg/l). The highest SSC were observed at the Tugnuy river in the Khilok basin (560 mg/l) and Dzhida mouth (200 mg/l).Both rivers have large mining complexes in the watershed (coal and copper-molybdenum correspondently).According to the Russian standard of permissible increase of SSC up to 0.25 mg/l in comparison with background levels (GN 2.1.5.1315 03), many rivers demonstrate elevated suspended load concentrations.

Significant increase of SSC and suspended load accordingly were observed at the Kharokhorin village at the Orkhon River (July, 2011) and at the Kharaa River upstream from Darkhan (June, 2012). At the first case the sediment load increased the average value in 10-fold times (SSC multiplied in 18 times from 160 to 2800 mg/l), at the flow peak it was 3000 tons per day due to intense rainfall, which were 50 mm of precipitation or 20 % of the average annual precipitation. At the Khaara River the from the 20th to 22nd of June precipitation was 28,1 mm (7 % of annual value) the SSC increased approximately in 40-times from 13.3 to 518 mg/l and suspended load was higher than 110-fold and reached almost 480 tons per day. Thereby the crucial factor in forming SSC is storm events. The maximal changes are typical for the mountain region, where soil erosion is high. The human activity (mining, agriculture, wastewater and so on) are superimposed on the natural suspended sediment concentration fluctuations, it caused SSC increasing several fold. Single hydrological events can increase the suspended load concentrations by at least one order of magnitude. It is important that sand fractions (>0.05 mm) dominated in sediment load during the peak and falling limb of the reported storm event whereas mostly clay particles contributed before and after storm event, As far as coarse material is usually regarded as a bed-material load which is associated (Alexeevsky et al 2008), mostly in-channel sources of sediment delivery causes massive sediment loading.

Significant excess of the maximum permissible concentrations for Cu and Fe is reported in the Selenga River at Zuunburen village, Mongolia. Other water quality indicators of the Selenga and Orkhon Rivers are admissible. High concentrations of Fe, Cu and reported at gauging station Naushki, close to the Russian-Mongolian border (on the Russian side of Selenga basin). Long-term average concentrations of Fe demonstrate 7.5-fold increase in comparison with maximum permissible concentrations; 6-fold increase for Cu. Maximum long-term values of these substances were 19, 11, 8-fold elevated respectively. At Murzino village located 25 km upstream from the Selenga River mouth the less excess of MPC was reported for Fe (6-fold), Cu (3-fold).

According to our field data, within Selenga basin most of the heavy metals are transported mainly in solid form associated with the suspended load. The increase of solid forms is particularly significant in areas with mining activities, especially gold-mining (Thorslund et al.

2012). Analysis of the mean chemical composition of the Selenga suspended fluxes showed its relative enrichment in comparison with the lithosphere averages by As, Bi, Cd, Mn, Pb, Zn, V, and Co. Thus most of the As and Zn are transported as dissolved load, whereas Bi, Cd, Mn, Pb, V, and Co are almost completely adsorbed by suspended solids. Mean content of Cu and Mo in the suspended matter corresponds to the world averages. The ratio of dissolved to suspended sediment for Cu is about 50 %, but for Mo it is much higher (up to 98 %). In particular, the sources of metals delivery into rivers are associated with processing plants in towns of Erdenet (Mongolia) and Zakamensk (Russia).

Analysis of the dissolved element composition revealed general enrichment of the Selenga River water by a number of chemical elements, which contents in some cases exceed MPC values for water fishery (Fig.3, 4). While increased values of Fe, Mn, Al could be explained by natural factors, elevated concentration of Cu, Mo, and Zn are caused by technogenic pollution. Analysis of the average content of trace elements in bottom sediments of the Selenga River showed their enrichment relative to the lithosphere by As, Cd, Sn, Sr, Ba, and W. Sediments, as in Mongolia, and in the Russian part of the Selenga basin, contain significant amounts of arsenic. One of its important sources in Mongolia is deposits of brown coal, which contains As among the impurities. Mercury, which is regarded as serious threat to

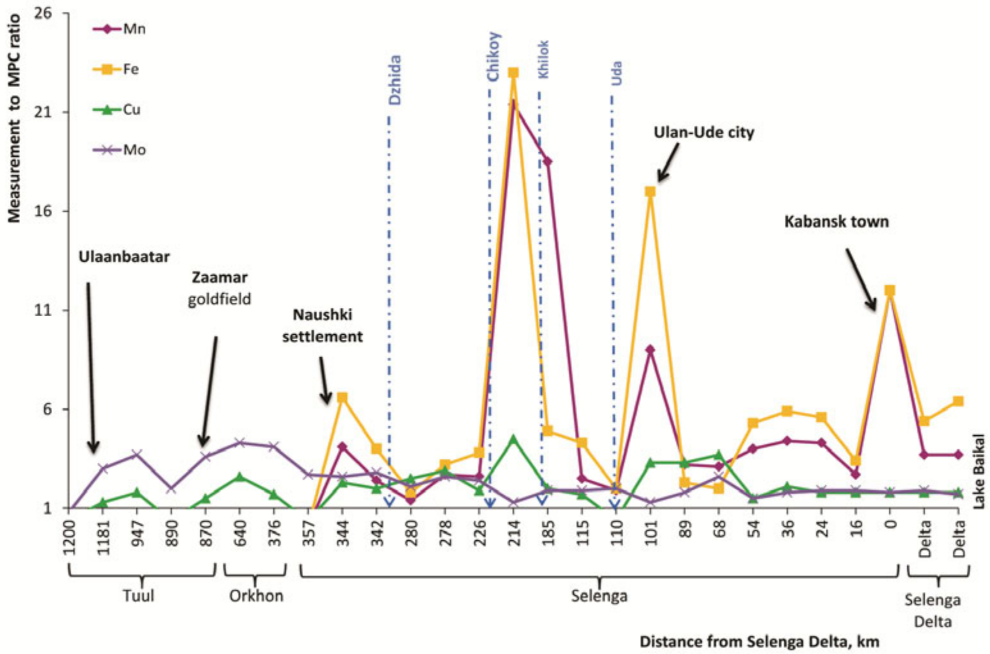

Fig.3: *Measurement to Maximum Permissible Concentrations ratio of Mn, Fe, Cu, Mo along the Tuul-Orkhon-Selenga River System*

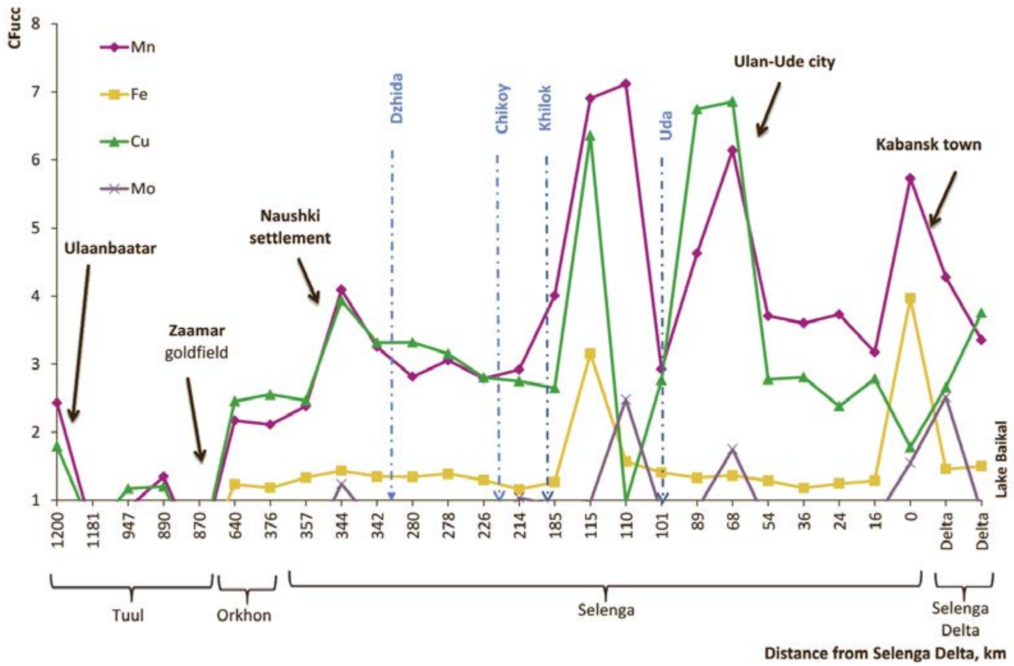

Fig.4: *Concentration Factors of Mn, Fe, Cu, Mo in suspended matter along the Tuul-Orkhon-Selenga River System*

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, highly elevated 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.

Hot spot assessment indicates that both as with water availability, water quality is strongly affected in the Tuul River. Due to poor maintenance, lack of spare parts, outdated equipment, and frequent power outages, at times waste water from the wastewater treatment plants in Ulaanbaatar might be released directly into the Tuul River without any treatment (Altansukh & Davaa 2011). As far as half of the Mongolian population is concentrated within its capital (Ulaanbaatar), this city is reported with a higher rates of environmental and water pollution in comparison with secondary cities of Mongolia (e.g. such as located in Selenga River basin Darkhan or Erdenet).

During low water flow periods of winter, the MPC of ammonium can be exceeded by more than 10-fold, certain organic substances by more than 40-fold (Altansukh & Davaa

2011). Concentrations of elements are relatively low upstream, but can increase by orders of magnitudes directly indicating a significant impact from the mining activities and Ulaanbaatar. Elevated loading of SSC and total phosphorus along the Tuul River downstream of Ulaanbaatar and Zaamar goldfield were found. In all mining regions of the Tuul River the fluxes of matter were observed to spike during rainfall. This leads to longitudinal increase of suspended loads and heavy metal mass flows.

Water from the Khangal River originated in the area of a large copper-molybdenum mine-mill complex Erdenet city had significantly elevated copper and sulfate concentrations. Dissolved ions concentration in the Khangal River is reported as up to 100 times higher than permissible levels (Baljinnyam et al. 2009, JangMin 2010). Due to low water discharge of the Khangal River (below 1 m^3/s in August, 2011), fast decrease of dissolved solids concentration is observed downstream along river network.

The similar impact within Russia is reported for the Dzhida River and especially its small tributary Modonkul which are distinguished by high values of heavy metals pollution from Zakamensk wolfram-molybdenum mining and processing factory. Increase in both dissolved and suspended forms is observed. Content of heavy metals in the suspended matter of the Modonkul River increases by 1-2 orders of magnitude compared with the background values. Suspended matter of the Dzhida River is also enriched with heavy metals.

4. DISCUSSION: IMPLICATIONS FOR FUTURE WATER RESOURCES ASSESSMENT AND MANAGEMENT

Even though only the upper parts of the Selenga basin are at present considered to be “water stressed”, the region as a whole is expected to face bigger competition over water resources. Socio-economic scenarios and climate projections, using six climate models driven by SRES emissions scenarios, predict generally an absence of change, or a slight increase of river runoff for the Selenga basin (Arnell 1999). At the same time, the increases tend to occur during the wet season and the extra water may not increase water availability during the dry season. Various authors predict a future increase in water demand for the region (Plusnin & Gunin 2001, Karthe this issue), with a 25 % increase of water consumption in 2015 in comparison with 2005 for the Russian part of the Selenga basin (Garmaev & Khristoforov 2010). As far as for Tuul river basin our results indicate as very low water availability, water stress of water resources availability in the area of Mongolia capital Ulaan-Baatar is mostly expected in the near future.

On the regional scale, water consumption problems is the urgent issue for the Mongolian government. The implementation of hydroprojects in the Mongolian part of the Selenga basin (as recently reviewed by Simonov, 2013) has the potential to become the main driver of water resources change in the near future. Hydropower plants are expected to be established at the Orkhon and Eg Rivers (Simonov, 2013) (Tab.3). The earliest feasibility studies on the construction of a 400 megawatts capacity hydro power plant on the Selenga River by the former Soviet Institute of Hydro Projects date back to the period of 1974-1975. This was followed by the assessment of building the Shuren Hydro Power Plant with a high capacity water storage reservoir. Shuren Hydro Power Plant on the Selenga River is of primary concern for diminishing the energy system strain in Mongolia, which would guarantee the water-resource power supply necessary for extended mining activities (Batimaa et al., 2011).

Another type of human impact which can cause significant changes of water resources availability in the region is Orkhon-Gobi Project. It envisions the diversion of water from the Orkhon and its transfer by a 1000 km long pipeline to Oyu Tolgoi, Tavan Tolgoi and other major mines in South Gobi. An announced 2.5 m^3/s of water will be diverted from the river (Simonov, 2013). Due to the fact, that the 95 % probability discharge of the Orkhon River is less than 10 m^3/s, this can lead to 25 % decrease of water runoff during low water periods in winter/spring. As far as these projects are mostly focused on the supporting mining industry, their implementation could lead for the even worth water availability both on regional and basin scale.

Tab.3: *Available information on projected dams in the Selenga River Basin within Mongolia (data from Simonov, 2013)*

Dam	River	Dam height H m	Average discharge Q_0 m^3/s	Average power U mW
Ulaan Ovoo	Orkhon	40	44	19
Khishiq Undur	Orkhon	75	44	26
Dulaankhar	Orkhon	115	40	37
Berkh	Orkhon	125	44.5	43.2
Ulaankhunkh	Orkhon	9	44.6	39.5–100
Ururrgut	Eg	95	99	62-200
Artsat	Selenga	75	183	84
Buren	Selenga	55	235	98
Shuren	Selenga	38	247	74.5

Our results mentioned above generally confirm the early inventory for surface water in Mongolia conducted in 2003 by BATSUKH, 2008. The main tributaries of Orkhon river (Tuul, Kharaa, Eroo) were morphologically changed and/or polluted due to mining activities. An the absence of routine monitoring of sediment loads precludes statistical analyses of the sediment trends. However, despite overgrazing, and with only one exception (upstream Orkhon river, near Kharkhorin villagethe studied rivers within Mongolia had lower SPM concentrations and carried lower suspended sediment loads during the campaigns of 2011 and 2012 than during previous field campaigns, even during the floods of the 2011 campaign. This result implies that other drivers, probably including hydrometeorological ones, must have a significant impact on the annual sediment fluxes. The mean annual discharge at some gauging stations within the Mongolian part of the basin (Buren Tolgoi, the Kharaa River) shows a significant decrease during the last decades, from an average of 21.8 m 3/s during the period 1990-1995 to only 8.8 m 3 /s for the years 1996-2002 (Hofmann et al. 2011). This decrease is primarily caused a reduction in precipitation and an increase in evapotranspiration during that period, though intensified water use for irrigation purposes may have contributed as well.

The results indicate that natural mass flows of heavy metals in dissolved form increased by an order of magnitude because of mining. However, the concentrations of suspended solids in the investigated rivers showed a stronger increase than for dissolved matter concentrations. The sources zones of pollutants are mainly located at industrial and mining centers, that supply vast amounts of material supplied from non-point (diffuse) sources - in-channel erosion and land use. Among the most heavy polluted rivers are the Tuul, Orkhon, Khangal within Mongolia and the Modonkul, Dzhida within Russia. As it was shown, in these rivers the maximum permissible concentrations of some elements or suspended sediment concentrations (SSC) can be exceeded more than 10-fold. In many places in these catchments water quality is not good enough for drinking water use and possesses a health risk for lifestock.

Turbid waters in rivers (e.g. Orkhon river) which are regarded by local citizens as an evidence of heavy pollution from mining sites located in the upstream reaches (personal communications to the citizens of Kharkorin village) could be related both to natural drivers (storm events) and human impacts. High concentrations of SSC (up to 1193 mg/l) were reported (Kuznetcov, 1955) for the studied rivers before the expansion of gold placer mining practices in the area. However, it is apparent from the close juxtaposition of floodplain mining activities and rivers (e.g. Tuul River, Eg River) that during flooding events large amounts of loose material could be flushed into the river (Stubbilefield et al 2005). Our results for the Orkhon River show that even in mining affected catchments, massive sediment loads during storm events may be associated with in-channel sources of sediment delivery and thus caused by bank collapses by elevated discharges.

High intensity discharge events can increase suspended load concentrations by at least one order of magnitude. Since the SSC was observed to distinctly increase at high flows, this suggests that the transport potential of sediment-associated pollutants can exhibit an increasing trend. The reported individual storm events during our field campaigns were associated with changes in heavy metals concentrations. During one storm event reported for Orkon River July 29-31 2011, the bulk concentrations (mg/l) were associated with an increase during the peak flow due to maximal SPM concentrations with (2,3 and 2,4 times increase for Fe and Al accordingly). The temporal variability that characterizes the hydrology of the region is consistent with river systems functioning under strong anthropogenic pressures (e.g. Meybeck and Vorosmarty 2005). Considering the combined effects of the increases in SSC and discharge in response to these high water levels, it is possible that relatively large portions of the sediment-associated pollutants can be transported during short periods of time.

Three implications for monitoring strategies for this transboundary catchment emerge from the obtained results. Firstly, a monitoring programmes that is based on the collection of infrequent water and suspended sediment samples may provide insufficient information to characterize the hydrological and sediment transport regime. Secondly, detecting possible long-term trends in water runoff or pollutant concentrations is the primary monitoring strategy as far as both water availability and water quality recently experience significant changes. Thirdly, characteristics of the event mean concentration (EMCs) (e.g. Sharma et al. 2012) from rainfall runoff provide principal information for the management of pollutants entering the river basin and its monitoring would be helpful to perform diffuse pollution modeling studies to evaluate the pollutant input into the river system.

The effects of the recent trends for future water resources are a key question for management strategies in the transboundary river system of Mongolia and Russia. Anthropogenic changes of river runoff and water quality are expected to become the primary factor of water availability stress. Political and economic dialogue between the 2 adjacent countries will be an essential determent for the status of water resources in the near future. Thus, the key challenge is on the development of strategies in international water law. According to international water law (The Helsinki Rules on the Uses of the Waters of International Rivers (Helsinki, 20 August 1966, ILA), The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 17 March 1992, UNTC) and The Convention on the Law of the Non-navigational Uses of International Watercourses (New-York, 1997, UN)), Russia and Mongolia have sovereign rights to the use water resources of Selenga River in their national interests and are responsible for attendant actions infringing on the interests of neighboring countries. Structures, impacting the water resources in the Selenga basin are becoming the subject of investigation of both Mongolia and Russia, and according to Heritage status of Lake Baikal – of the whole international community.

From this perspective the main concern is the implementation of sustainable water use projects and a leagal framework for the mining industry which potentially threatens both water availability and water quality. Mining concessions overlap with current or planned hydropower projects and have an impact on economic growth, which is the key factor for increased water consumption in the region. From this point, a dialogue on water between Russia and Mongolia should be built within frames of general socio-economic development of the region. The issue of dam creation in the Selenga and main its tributaries is becoming a source of tension between Mongolia and Russia with growing concern on water resources impact. Estimates of hydropower dams construction sequences (water balance alterations, river runoff decrease, flow regimes and sediment load changes due to sediment starving, flood events below barriers, channel bed and banks erosion with bed load increase) are of crucial importance for water resources assessments. Recently all the predictions of future water resources scenarios due to dam construction are characterized by subjective evaluations. For example, managers of the Shuren Hydropower dam project stated that the dam power station is expected to help manage the rising power demand in Mongolia, should decrease greenhouse gasses by 700 thousand tons and save 300 thousand tons of coal a year (Shuren Hydropower 2013). On the other hand, environmentalists (Simonov, 2013) warn about social and environmental impacts which are rather unclear due to absence of exact data about reservoir and dam sizes.

Future management of joint water resources of the Selenga River Basin could be based on market-based mechanisms (Valentini et al. 2004, Khristoforov 2010). Water supply services at the international level must be paid for by the interested countries. Ranges of water discharges, dissolved and suspended sediment concentrations, water temperature should be determined for each river in form of natural permissible levels. These limits should provide sufficient amount of water, relevant water quality, a low level of dangerous hydrological processes, help the conservation of water communities and further determine consumption and pollution limits which regulate water resources use of both Russia and Mongolia. From this perspective possible variants of water resources management for Selenga basin (in case of proved negative impacts from projected dam construction) can be connected with the establishment of fees for denied profit from non-used hydropower potential. Among possible economic alternatives are the transfer hydropower from Angara-Enisey dams and gasoline threads from Russia to Mongolia. At the same time, the introduction of this approach is a rather comprehensive issue, due to the lack of experience in the implementation of market-based mechanisms in the region.

5. CONCLUSION

Insight into water resources of the Selenga River Basin evidences a high spatial instability of water availability and quality. The upstream part of the Tuul River catchment within Mongolia is considered to be “water stressed” with a water availability of 969 m^3/capita/yearFew rivers in the Selenga basin were ranked as “slightly polluted” according to the norm of surface water freshness ranks by the guidelines and standards of water in Mongolia (Batsukh et al. 2008). Along the lower parts of the Tuul, Orkhon, Modonkul and Dzhida rivers maximum permissible concentrations of some elements can be exceeded more than 10-fold. One important methodological aspect of this work was to show that suspended sediment concentration in case of the Selenga River is an important factor for water quality, since it accounts for more than 90% of the total river-borne flux of elements such as Bi, Cd, Mn, Pb, V, and Co. The increase of solid transport is particularly significant in areas with mining activities, especially gold-mining. We suggest that local to regional transformation and enrichment processes in combination with suspended sediment transport from numerous existing upstream mining areas and large industrial centers (especially Ulaanbaatar and Erdenet in Mongolia and Ulan-Ude and Zakamensk in Russia) contribute to high concentrations of dissolved heavy metals in downstream parts of the Selenga River, including its delta area at Lake Baikal. However, suspended sediment concentrations are much higher than dissolved concentrations. The overall impact of the mining activities on downstream water systems must hence be dominated by the fate of the heavy metals that are attached to particles in suspension.

Future trends on water resources quality and quantity will depend strongly on human activities. The most serious consequences for water resources availability and quality are expected from the installation of hydropower and water- transfer projects within Mongolia. The announced 2.5 m^3/s diversion from Orkhon to Gobi will cause a 25 % decrease of runoff during low water periods (winter-spring) in the Orkhon River. As far as mining concessions overlap with current or planned hydropower projects and have an impact on economic growth trends the future water resources will follow general socio-economic trends in both Mongolia and Russia.

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Authors:

Dr. Sergey Chalov
Department of Hydrology
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
srchalov@rambler.ru

academician RAS Nikolay Kasimov
Department of Landscape Geochemistry and Soil Geography
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
secretary@geogr.msu.ru

Dr. Mikhail Lychagin
Department of Landscape Geochemistry and Soil Geography
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
lychagin2008@gmail.com

Ekaterina Belozerova
Department of Hydrology
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
ekv.belozerova@gmail.com

Galina Shinkareva
Department of Landscape Geochemistry and Soil Geography
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
galina.shinkareva@gmail.com

Philipp Theuring,
Department Aquatic Ecosystem Analysis and Management (ASAM)
Helmholtz Centre for Environmental Research - UFZ
Brückstrasse 3a
D-39114 Magdeburg, Germany
philipp.theuring@ufz.de

Anna Romanchenko
Department of Hydrology
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
a.a.romanchenko@gmail.com

Prof. Nikolay Alexeevsky
Head of the Department of Hydrology
Faculty of Geography
Lomonosov Moscow State University (LMSU)
GSP-1, Leninskie Gory 1
119234 Russian Federation, Moscow
n_alex50@mail.ru

Prof. Endon Garmaev
The Baikal Institute of Nature Management
ul. Sakhayanovoy, 6
Ulan-Ude
garend1@yandex.ru