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SUSPENDED AND DISSOLVED MATTER FLUXES IN THE UPPER SELENGA RIVER BASIN

ABSTRACT. We synthesized recent field-based estimates of the dissolved ions (K^+ Na^+ Ca^{2+} Mg^{2+} Cl^- SO_4^{2-} HCO_3^-), biogens (NO_3^-, NO_2^-, PO_4^{3-})(C, mg/l), heavy metal (Fe_{sum}, Mn, Pb) and dissolved load (DL, kg/day), as far as suspended sediment concentration (SSC, mg/l) and suspended load (SL, kg/day) along upper Selenga river and its tributaries based on literature review and preliminary results of our 2011 field campaign. The crucial task of this paper is to provide full review of Russian, Mongolian and English-language literature which concern the matter fluxes in the upper part of Selenga river (within Mongolia). The exist estimates are compared with locations of 3 main matter sources within basin: mining and industry, river-bank erosion and slope wash. The heaviest increase of suspended and dissolved matter transport is indicated along Tuul-Orkhon river system (right tributary of the Selenga River where Mongolia capital Ulanbaatar, gold mine Zaamar and few other mines are located). In measurement campaigns conducted in 2005, 2006 and 2008 the increase directly after the Zaamar mining site was between 167 to 383 kg/day for Fe, between 15 and 5260 kg/day for Mn. Our field campaign indicated increase of suspended load along Tuul river from 4280 kg/day at the upstream point to 712000 kg/day below Ulaanbaatar and Zaamar. The results provide evidence on a potential connection between increased dissolved and suspended matter fluxes in transboundary rivers and zones of matter supply at industrial and mining centers, along eroded river banks and pastured lands. The gaps in the understanding of matter load fluxes within this basin are discussed with regards to determining further goals of hydrological and geochemical surveys.

KEY WORDS: mass flow, suspended and dissolved matter transport, transboundary rivers

INTRODUCTION

Matter supply into water systems affects humans and the natural environment world-wide. Both natural processes, such as dissolution of substances from weathering soil and rock, and anthropogenic activities, particularly from the agriculture and industry sectors (UNEP, 2009), can cause suspended and dissolved matter transport. Suspended and dissolved particles transported by river flow can originate either from input into channels from drainage basins (basin-sourced sediment) or from particle detachment within the channels themselves from their beds and banks (channel-sourced sediment). On any river one can find intensively eroded channel banks and recently formed accumulative within-channel bars. The different sources and characteristics of the channel particles, as well as the different river processes, induce heterogeneities in particle compositions and ultimately determine the unequal fall velocities and sediment distributions. Vertical sediment fluxes significantly correlate with transporting capacity. Near-bottom sediment exchange is the result of general laws of matter movement which are governed by the turbulent diffusion equation [Alexeevsky, 2006]:

$$\frac{\partial s}{\partial t}=\frac{A}{\rho}\left(\frac{\partial^2 s}{\partial x^2}+\frac{\partial^2 s}{\partial y^2}+\frac{\partial^2 s}{\partial z^2}\right)- , \qquad (1)$$
$$-\left(v\frac{\partial s}{\partial x}+u\frac{\partial s}{sy}+w\frac{\partial s}{\partial z}\right)-\omega\frac{\partial s}{\partial y}$$

where the different terms reflect impacts of turbulent transport, advection, dispersion, convection and gravity, respectively, and A is the turbulent exchange coefficient, ρ – water density, ***s*** – suspended sediment concentration at the point, ***u***, ***v***, ***w*** – local velocity vectors. In basin-scale transport assessments, a crucial task is connected with the quantification of the advection and dispersion terms. Key challenges are furthermore to identify the exact locations of main sources in river basins, and the different contributions of natural and anthropogenic impacts.

Understanding of matter fluxes along river system depends on the monitoring system. In transboundary river systems, single and coherent monitoring is often incomplete due to administrative reasons. Large efforts in terms of field measurement campaigns and (numerical) transport modeling are then typically needed for relevant pollution prediction and prevention. The transboundary river system of Selenga is particularly challenging, being for instance the biggest tributary of Lake Baikal, the largest freshwater reservoir of the world. Selenga River contributes with about 50% of the total inflow into Baikal. It originates in the mountainous part of Mongolia and then drains into Russia. There are numerous industries and agricultural activities within the Selenga drainage basin that affect the water quality of the river system. Historically the principal land use is grazing. Other land uses include mining, forestry, and row crop agriculture. In the Mongolian part of the basin, waters of the Orkhon river, downstream Tuul river, and the Eroo rivers are reported to get impacted [Integrated Water, 2010]. Orkhon, Tuul, Kharaa and Khans are experiencing increased pollution by urbanization and industrial activities within the basin [MNE, 2007; Batimaa et.al, 2011]. At the same time rivers drain broad alluvial valleys and thus are distinguished by high rates of bank erosion. Matter fluxes of the rivers is effected by both natural (bank erosion) and anthropogenic (mining and slope wash from the deforestated lands and pastures) drivers.

Suspended and dissolved matter fluxes have been reported to increase in recent times [Boyle et al., 1998; Khazheeva et al., 2006].

At the same time, constant observations of sediment and dissolved matter mass flows in the upper Selenga basin (within Mongolia) have never been performed [Ecosystems..., 2003]. Therefore field surveys are considered to be the main source of information for suspended and dissolved matter fluxes analyses. Although extensive research has been conducted on the water quality of Lake Baikal and on the Russian reaches of the Selenga river [Munguntsetseg, 1984; Ubuganov et al., 1998; Dambiev and Mairanovsky, 2001; Garmaeva, 2001; Korytny et al., 2003; Khazheeva et al., 2004], limited information is available on the conditions of the upstream basin, in Mongolian rivers. Few studies have addressed matter movement in small catchments [Dallas, 1999; Onda et. al, 2007]. Long-term abundant research has been performed by IWRM MoMo project in the Khara 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. Full review of the single observations of water quality and suspended load of the whole Mongolian part of the basin was done earlier by Soviet [Kuznetsov, 1955; Hydrological regime..., 1977] and Mongolian scientists [Batimaa, 2000]. Limited field campaigns have recently focused on the investigation of the whole Selenga river basin [Stubblefield et.al, 2005; AATA, 2008; Baljinnyam et.al, 2009; Integrated water..., 2010; MCA 2011] and were recently complemented by our field works in 2011. The latter included measurements in the Selenga river (Mongolia and Russia) in 2011 to understand current sediment and dissolved loads of the transboundary river system during summer floods.

In the current paper we mainly focus on combining in-situ measurements with syntheses of field study results in the upper Selenga basin. A main difficulty of this work was to interpret and combine suspended sediment concentration (SSC) and dissolved concentration data and river discharge data (Q) in such a way that mass flows (Mf) could be estimated. The difficulty is generally to find data with sufficient spatial and temporal resolution, such that for instance the sampling points and sampling time for the concentration measurements are consistent with existing discharge measurement data series. Uncertain mass flow estimates of water-borne pollutants are an issue in many regions of the world due to shortcomings within monitoring systems [e.g. Zhulidov et al., 2003; Bring and Destouni, 2009].

This paper focuses on generating a contemporary full review of hydrochemical data, illustrating the suspended and dissolved matter transport. The paper aims at providing an understanding of the sources of matter input into river systems and its qualitative assessment. The work more specifically aims at quantifying downstream impacts of various sources based on limited monitoring data, a condition that the presently considered region shares with many fast developing regions of the world. Understanding of diffuse as well as point source zones of matter supply is essential to the knowledge needed for more detailed impact assessments and management decisions, regarding remediation planning and measures.

METHODS AND MATERIAL

The study area covers the upper part of the Selenga basin within Mongolia (Fig. 1). The Mongolian portion of the Selenga River watershed is composed predominantly of broad alluvial valleys flowing through steppe grasslands with source areas in taiga and mountain ecosystems. 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. Our field campaign was conducted during the summer runoff increase and thus under the conditions of significant increase in sediment and dissolved matter concentrations.

Existing estimates of suspended and dissolved solids concentration were synthesized and analyzed in terms of spatial distribution in river basin, its temporal variability and possible linking with various sources of matter supply. We used gathered data to assess mass flow in a river which represents the matter mass that passes through a cross section (also referred to as a control plane) of the river per unit of time. Mass flows are products of local concentrations and discharges, according to

$$Mf = C_i Q_i, \quad (2)$$

where C_i is the concentration (SSC or C) at the control plane for (given) time t_i, and Q_i is the water discharge through the control plane for (given) time t_i. Time period was applied as 1 day, therefore the MF (both DL and SL) was estimated as

$$Mf = 86\,400\, C_i Q_i. \quad (3)$$

The analyzed dissolved and suspended matter concentrations (dissolved and particulate) were synthesized from our 2011 measurements and reviews and reports devoted to measurements campaigns in rivers of the region [Kuznetsov, 1955; Votincev K.K. et al., 1965; Hydrologic regime..., 1977; Stubblefield et al., 2005; AATA 2008; Integrated Water..., 2010]. Gathered information covered observations at Tuul, Orkhon, Selenga, Eroo, Khangal and Egiin-Gol rivers at 14 gauging stations.

In our 2011 (July–August) field campaign water samples for total suspended sediment concentration (SSC) assessment were collected from the rivers of the Selenga basin in Mongolia. The hydrological field measurements included discharge, turbidity (T), suspended sediment concentration (SSC) and major dissolved ions concentration (Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}, HCO_3^-). This paper does not introduce to the results of our samples analyses of biogens (nitrogen and phosphorous) and heavy metals (such as Zn, Cu, Ni, Cd, Pb) content in water and in sediments (bed and suspended).

In all reported works the discharge measurement and sampling procedures followed standard methods. Depth-integrated water samples were collected with a GR-16M bottle sampler at the midstream. Turbidity was measured on site using portable "HACH" 2100P meter. To study SSC the samples were filtered through pre-weighed membrane and paper filters with the "Millipore" filtration system. The samples were then oven-dried and re-weighed. Discharges were determined from bridges, by boat or by wading in two ways. In the first case, flows were measured with a hydrometric propeller ISP-1 at the one-fifth depths of each width increment. The total water discharges were calculated by multiplying the discharge flow velocities with cross-sectional areas of the rivers. The total sediment discharges were calculated by multiplying sediment-load velocities with average SSC-values and cross-sectional areas of the rivers. When the depth was more than 1.5 meters the Acoustic Doppler Profiler (ADP) was used.

For the present study we used information only from the stations, where any relevant hydrochemical measurements have earlier been performed. Observations at 14 stations from total 35 were used for present analyses, comprising data on suspended sediment load (SSC and SL) and concentration of dissolved ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}, HCO_3^-). Documented field monitoring stations are located at Tuul river (T): upstream from Ulaanbaator (T-1), at Ulaanbaatar (T-2), downstream from Ulaanbaatar (T-5), upstream from Zaamar goldfield (T-3), at Zaamar (T-4) and near the confluence with Orkhon river (T-6); Orkhon river at Kharkhorin Town (O-1), downstream from confluence with Tuul river (O-6),downstream from confluence with Tuul river (O-8) and above Selenga river (O-9); low reach of Egiin-Gol river (EG), low reach of Eroo river (ER) and Khangal river downstream from Erdenet (H-1) and Selenga river near Hutyk village (S-1).

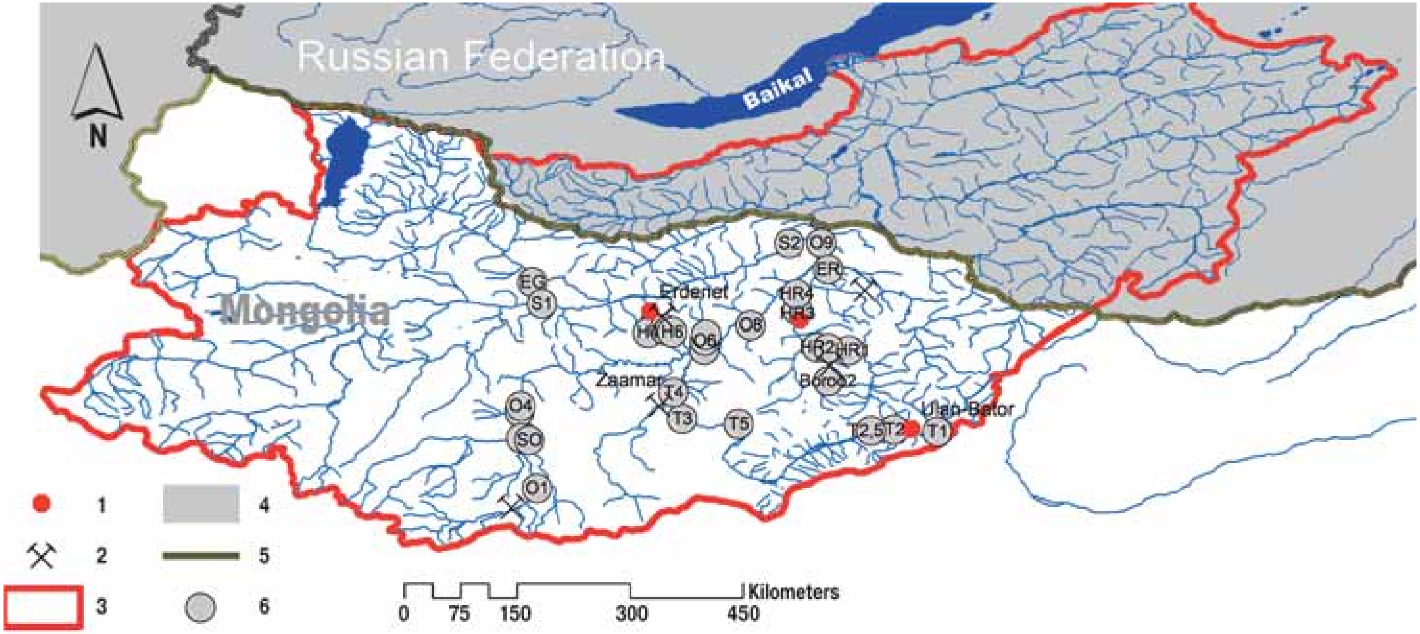

Fig. 1. Sampling points and measured turbidity in the upper Selenga river basin during 2011 field campaign:

1 –cities; 2 – mining areas; 3 – Selenga basin watershed; 4 – territory of Russian Federation; 5 – state border; 6 – sampling points

CONTEMPORARY ASSESSMENTS OF SUSPENDED AND DISSOLVED MATTER FLUXES

The synthesized data concerning suspended sediment load is presented in table 1, whereas table 2 is devoted to dissolved load. Analyses of the contemporary spatial distribution of water quality parameters in the upper Selenga rivers demonstrate, that there are few driving forces in supply of material into river networks. The main sources are primarily associated with mining activities, in-channel processes and slope erosion (Fig. 2).

According to existing estimates, considerable increase of dissolved load is observed along the Tuul river. Mass flows are relatively low upstream, but can increase by orders of magnitudes directly indicating a significant impact from the mining activities, Ulaanbaatar

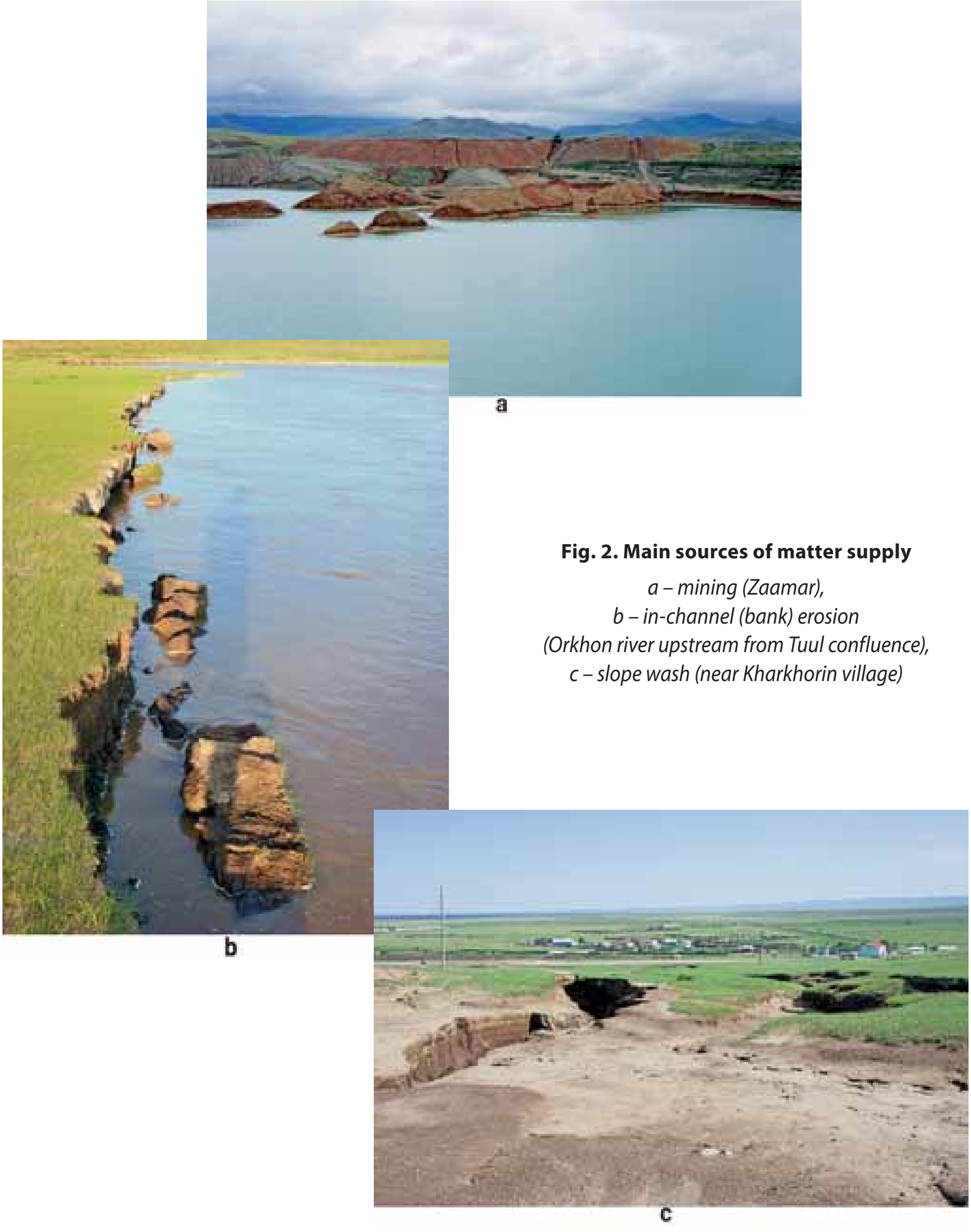

Fig. 2. Main sources of matter supply

a – mining (Zaamar),
b – in-channel (bank) erosion
(Orkhon river upstream from Tuul confluence),
c – slope wash (near Kharkhorin village)

Table 1. Estimates of suspended sediment concentration (SSC) and suspended load (SL) along upper Selenga rivers

Station	Description	Date	SSC, mg/l	Q, m^3/s	Mass flow, kg/day, 10^3	Reference
T-1	Tuul river upstream from Ulaanbaatar	23 Jul 2011	1,68	29,5	$4,3 \cdot 10^3$	Present study
T-2	Tuul river downstream from Ulaanbaatar	1959–61	41,8	55,0	$198,6 \cdot 10^3$	Hydrologic regime..., 1977
		25 Jul 2011	5,86	22,8	$11,5 \cdot 10^3$	Present study
T-3	Tuul river upstream from Zaamar	27 Jul 2011	107	33,4	$308,8 \cdot 10^3$	Present study
T-4	Tuul river at Zaamar	1935	330	34,0	$969,4 \cdot 10^3$	Hydrologic regime..., 1977
		26 Jul 2011	289	28,5	$711,6 \cdot 10^3$	Present study
T-6	Tuul river upstream confluence with Orkhon river	3 May 1934	79,0	17,7	$120,8 \cdot 10^3$	Kuznetsov, 1955
		4 Aug 1934	643	65,3	$3627,8 \cdot 10^3$	Kuznetsov, 1955
		26 Aug 1934	716	33,5	$2072,4 \cdot 10^3$	Kuznetsov, 1955
		17 Oct 1934	11,0	20,0	$19,0 \cdot 10^3$	Kuznetsov, 1955
		7–12 Aug 2001	59	11	$56,1 \cdot 10^3$	Stubblefield et.al, 2005
		18–24 Aug 2001	74	15	$95,9 \cdot 10^3$	Stubblefield et.al, 2005
		6 Aug 2011	184	29,2	$464,2 \cdot 10^3$	Present study
O-1	Orkhon river at Kharkhorin Town	1964–65	41,7	32,9	$118,5 \cdot 10^3$	Hydrologic regime..., 1977
		28–30 Aug 2011	1261	–	–	Present study
O-6	Orkhon river upstream from the confluence with Tuul river	7–12 Aug 2001	68	25	$146,9 \cdot 10^3$	Stubblefield et.al, 2005
		18–24 Aug 2001	27	27	$63,0 \cdot 10^3$	Stubblefield et.al, 2005
		6 Aug 2011	215	–	–	Present study
O-8	Orkhon river downstream from the confluence with Tuul river	5 May 1934	121	22,3	$233,1 \cdot 10^3$	Kuznetsov, 1955
		6 Jul 1934	227	71,4	$1400,4 \cdot 10^3$	Kuznetsov, 1955
		28 Jul 1934	1695	283	$41444,8 \cdot 10^3$	Kuznetsov, 1955
		17 Aug 1934	144	88,2	$1097,3 \cdot 10^3$	Kuznetsov, 1955
		19 Oct 1934	9,70	61,9	$51,9 \cdot 10^3$	Kuznetsov, 1955
		7 Aug 2011	141	–	–	Present study
O-9	Orkhon river above confluence with Selenga river	1961–62	110	81,9	$778,4 \cdot 10^3$	Hydrologic regime..., 1977
		7–12 Aug 2001	39	70	$235,9 \cdot 10^3$	Stubblefield et.al, 2005
		18–24 Aug 2001	37	125	$399,6 \cdot 10^3$	Stubblefield et.al, 2005
		11 Aug 2011	63,4	250	$1369,4 \cdot 10^3$	Present study
S-1	Selenga river near Hutyk village	18–24 Aug 2001	11,5	434	$431,2 \cdot 10^3$	Stubblefield et.al, 2005
		2 Aug 2011	114	178	$1753,2 \cdot 10^3$	Present study
EG	Egiin-Gol river, downstream	7–12 Aug 2001	27	–	–	Stubblefield et.al, 2005
		2 Aug 2011	83,2	–	–	Present study
ER	Eroo river upstream confluence with Orkhon river	7–12 Aug 2001	7	26	$15,7 \cdot 10^3$	Stubblefield et.al, 2005
		18–24 Aug 2001	32	51	$141,0 \cdot 10^3$	Stubblefield et.al, 2005
		11 Aug 2011	7,26	51,1	$32,1 \cdot 10^3$	Present study

Table 2. Estimates of dissolved solid concentrations along upper Selenga rivers

Station	Description	Date	DSC, mg/l														Reference
			Σions	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	Fe_{sum}	Mn	Pb	NO_3^-	NO_2^-	PO_4^{3-}	
T-1	Tuul river upstream from Ulaanbaatar	Jun 2008	–	10,2		2,4	0,2	6,0	0,0	8,9	131,0	–	–	4,2	0,4	–	Integrated Water..., 2010
		Jul 2009	–	10,0		2,4	0,1	7,0	0,0	3,6	–			4,8	0,1	–	
		23 Jul 2011	–	12,1	6,8	0,6	2,8	3,7	–	–	–	–	–	–	0,2	0,20	Present study
T-2	Tuul river at Ulaanbaatar	5 Jun 1953	54,8	0,5	12,5	0,9	2,4	7,4	31,1	–	–	–	–	–	–		Hydrologic regime..., 1977
		20 May 1963	91,1	15,4		10,1	0,6	14,2	2,0	48,8	–	–	–	–	–	–	
		27 Jul 1954	51,0	0,6		10,2	2,2	7,5	2,1	27,4	–	–	–	1,0	–	–	
		28 Jun 1956	111,4	18,4		8,0	3,6	11,6	15,0	54,8	–	–	–	–	–	–	
		15 Oct 1971	449,3	35,6		51,9	11,4	31,6	14,8	298,8	–	–	–	5,2	–	–	
		16 Mar 1963	370,1	0,5		60,0	22,8	14,2	4,2	268,4	–	–	–	–	–	–	
		Jun 2008	–	12,0		2,4	0,2	9,0	0,0	7,1	178,6			6,4	0,0	–	Integrated Water..., 2010
		Jul 2009	–	20,0		1,2	3,1	20,0	0,0	17,8	102,2	–	–	24,2	0,2	–	
		24 Jul 2011	–	0,7	9,5	1,1	2,4	4,5	–	–	-	–	–	–	3,1	3,10	Present study
T-5	Tuul river downstream from Ulaanbaatar, near Lun	Jun 2008	–	20,0		4,9	0,2	29,4	0,0	21,3	222,5	–	–	50,9	0,8	–	Integrated Water....., 2010
		27 Jul 2011	–	2,55		9,4	17,4	3,1	10,8	11,2	–	–	–	–	–	3,2	Present study
T-3	Tuul river upstream from Zaamar	27 Jul 2011	–	1,7	18,7	3,4	11,9	12,9	–	–	–	–	–	–	3,0	3,00	Present study
		Jun 2008	–	31,1		22,5	0,2	36,0	0,0	42,6	254,7	–	–	53,8	0,0	–	Integrated Water..., 2010
T-4	Tuul river at Zaamar	Jun 2008	–	30,1		23,7	0,2	20,1	0,0	39,1	255,0	–	–	40,5	0,3	–	Integrated Water..., 2010
		Jul 2008	–	–		–	–	–	–	–	170,0	25.7	0.34	–	–	–	AATA, 2008
		26 Jul 2011	–	2,1		13,5	20,1	3,9	11,4	15,4	–	–	–	–	–	–	Present study
T-6	Tuul river before confluence with Orkhon river	Jul 2008	–	-		–	–	–	–	–	240,0	413	0,4	–	–	–	AATA, 2008
		6 Aug 2011	–	1,8	22,6	4,7	13,5	17,8	–	–	–	–	–	–	4,6	4,64	Present study

Continue table 2

Station	Description	Date	DSC, mg/l														Reference
			Σions	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	Fe_{sum}	Mn	Pb	NO_3^-	NO_2^-	PO_4^{3-}	
O-1	Orkhon river at Kharkhorin Town	Jun 2008	–	30,1		2,4	4,0	16,0	0,0	35,5	410,9	–	–	–	30,1	–	Integrated Water..., 2010
		29 Jun 2011	–	1,54	9,3	1,9	1,3	5,3	–	–		–	–	–	–	–	Present study
O-8	Orkhon river downstream from the confluence with Tuul river	25 Sep 1971	266,0	23,2		34,0	9,2	6,3	25,5	167,8	–	–	–	–	–	–	Hydrologic regime..., 1977
		October 2005	–	–		–	–	–	–	–	53,0	–	–	–	–	–	Integrated Water..., 2010
		June 2006	–	–		–	–	–	–	–	80,9	–	–	–	–	–	
		7 Aug 2011	–	2,15	22,9	5,1	3,7	11,3	–	–		–	–	–	4,9	4,92	Present study
O-9	Orkhon river above Selenga river	Apr–Jul 1945, Mar, Jun 1946	–	12,6-22,4		21,1–38,5	4,1–7,7	4,2–12,6	10,8–26,4	91,5-152,5	–	–	–	–	–	–	Votincev K.K. et al., 1965
		Jul – Aug 2002–2009	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Bayaraa U., 2010
		Jul 2007	–	13,9		30,1	7,3	5,3	17,3	134,2	52,4		–	–	0,0	0,0	Integrated Water, 2010
		12 Aug 2011	–	2,0	23,2	5,3	4,1	11,5	–	–		–	–	–	–	–	Present study
S-1	Selenga river near Hutyk village	Jul 2007	–	12,4		40,1	12,2	3,6	27,0	170,8	122,9		–	–	0,2	–	Integrated Water..., 2010
		2 Aug 2011	–	1,3	21,5	4,1	1,5	8,2	–	–		–	–	–	–	–	Present study
EG	Egiin-Gol river, downstream	1959-74	77,6–377,8	4,8-31,3		5,0-44,1	1,5-15,8	14,2	4,0-10,0	36,6-268,4	–	–	–	–	–	–	Hydrologic regime..., 1977
		2 Aug 2011	–	1,7	33,1	6,3	0,5	13,6	–	–		–	–	–	–	–	Present study
ER	Eroo river upstream confluence with Orkhon river	Jul 2007	–	7,3		14,0	3,0	3,6	4,0	67,1	83,7		–	–	0,0	–	Integrated Water..., 2010
		11 Aug 2011	–	1,1	9,7	1,9	1,2	4,6	–	–	–	–	–	–	–	–	Present study
H-1	Khangal river downstream from Erdenet	Jul 2007	–	23,3		134,3	57,8	32,0	300,0	292,8	101,0	–	–	–	0,0	–	Integrated Water..., 2010
		Jul 2009	–	115,2		38,9	2,8	200,0	0,0	26,6	200,8	–	–	–	0,2	–	
		4 Aug 2011	–	2,5	33,9	111,5	36,7	33,9	16,8	263,6	0,84		–		7,11		

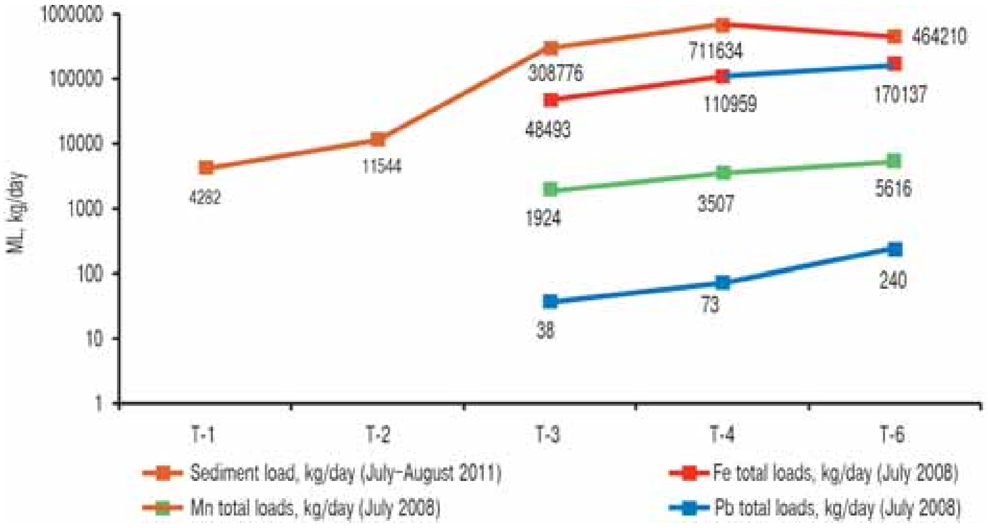

Fig. 3. Estimated mass flows (kg/day) of total suspended and dissolved load at five different sampling points along the Tuul River (numbers according to tables 1–2)

and agricultural sector. More specifically, the three considered measurement campaigns conducted in 2005, 2006 and 2008 [AATA, 2008] showed that the increase directly downstream of the mining site (from dissolved concentrations) were found to be between 167 to 383 kg/day for Fe, between 15 and 5260 kg/day for Mn, and between3.6 to 4.6 kg/day for Pb, compared with values upstream the site. Previously [Stubblefield et.al, 2005] reported increase of SSC and total phosphorus along Tuul river. Our field campaign indicated increase of suspended load along Tuul river from 4280 kg/day at the upstream point to 712000 kg/day below Ulaanbaatar and Zaamar (Fig. 3).

Rapidly changing hydrological characteristics of rivers prevent adoption of results of in-situ sampling for temporal analyses. At the points where measurements were conducted several time in the 20th and 21st centuries (e.g. T-6, O-8) the significant fluctuations of both SSC and DSC are indicated. At the Tuul river upstream from the confluence with Orkhon river (T-6 station) measurements were done 7 times, SSC varied between 11 mg/l at 7 Oct 1934 to 716 mg/l at 26 Aug 1934. Maximal SSL was $3627,8 \cdot 10^3$ kg/day at 4 Aug 1934 indicating the significant impact of water discharge on sediment load.

Reported values of major ions concentration evidence up to 5 times change between measurements. For example, at the downstream reach of Orkhon river (above confluence with Selenga river) (O-9 station) major ions concentration varied up to 6 times between Jul, 2009 and Aug 2011. Simultaneously ions concentrations were highest during low water period [Votincev et al., 1965], and decreased significantly during high water periods (e.g. our field measurement during August 2011).

The following part of the paper is devoted to the analyses of main sources of matter supply within basin.

POINT SOURCES

Mining and industry

In recent years, exploration for natural resources has increased rapidly. Many river basins are used intensively for mining of gold, silver, and coal, supplying also precious stones, gravel, and other natural resources. A total of 784 enterprises are engaged in mining, of which 204 small-scale gold mining companies are operating on 6,065,298 hectares of land [Batimaa, 2011]. Some of the gold miners are reported to use mercury in the gold extraction. The surface water inventory revealed that gold mining activity affects 28 rivers in 8 provinces of Mongolia. Many square kilometers of the river terraces are heavily disturbed. Flooding could breach thin strips of land separating dredge pits from river channels, resulting in massive sediment loading.

The most significant evidences of mining impact on suspended and dissolved matter fluxes of upper Selenga rivers exists along the Tuul river where the Zaamar Goldfield is located. The gold mining in the Zaamar Goldfield has been active since the seventies [Karpoff and Roscoe, 2005]. Today the area has the greatest gold production in Mongolia with 147 tons produced from 1998 to 2007 [AATA, 2008]. The largest and most recent gold mine in the Zaamar Goldfield is the Big Bend Placer Gold Mining Project (Big Bend).

Besides gold mines, Ulaanbaatar with its livestock and tourist camps is regarded to be a main source of matter supply into the river [Batimaa et al..., 2011]. There are currently 26 wastewater treatment plants in Ulaanbaatar, but 14 are not functioning [Tuvshinjargal, 2009]. All of the remaining 12 treatment plants are discharging into the Tuul river. The observed data from different sources (table 1–2) demonstrate elevated loading of SSC and total phosphorus along Tuul river downstream of Ulaanbaatar and Zaamar goldfield. 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. Due to the incorporation of local discharges with local concentrations, suspended loads and mass flows are reported to increase up to 100 times.

Another example of mining activities impact on water quality was observed in the mountainous headwaters of the Yeroo River [Stubblefield et al., 2005].Tributary drainages undergoing mining had total phosphorus concentrations 8 to 15 times higher than the main stream. SSC was 7 to 12 times higher, and turbidity was 8 times higher.

Special type of material supply is reported in the area Erdenet city which is the second largest industrial and mining city with 100 000 inhabitants in Mongolia. Today the Erdenet Mining Corporation (EMC) extracts 25.5 million tons of ores and produces 500 thousand tons of copper and 2 thousand tons of molybdenum concentrates per year. Significant increase of dissolved ions concentration in the Khangal river which originated from Erdenet and drained by wastewaters from mining ponds was up to 100 times in comparison with background values [Baljinnyam et.al, 2009; Integrated water..., 2010]. We also indicated elevated loading of dissolved ions (see Table 2). At the same time low water discharge of the Khangal river (below 1 m^3/s in August, 2011) provide fast decrease of dissolved solids concentration downstream along river network.

DIFFUSE SOURCES

In-channel erosion

Despite the fact that different hydrologic characteristics of Mongolian river systems are widely studied by Mongolian and foreign scientists, there are still many unsolved problems related to their channel processes. To the best of our knowledge and based on our literature search, no research have ever been conducted on the allocation and spread of different types of river channels, no available estimations on intensity and direction of the horizontal channel deformations, no data on different characteristics of erosion and accumulation processes in river valleys and watersheds. The only one major scientific work in this area is the PhD thesis of Mongolian scientists Natsag Zhamsrangiyna, regarding "River profiles and the formation of river channels in Selenga basin in Mongolia". This work was done in the mid of 70s on the Faculty of Geography, Lomonosov Moscow State

University. Being a research fellow in the Russian Academy of Sciences, Institutes of Geography and Permafrost, Natsag was an active participant of joint Russian-Mongolian expeditions. That allowed him to use field data on channel morphology, composition, distribution of river sediments, and hydrological characteristics. In the dissertation and scientific papers, Natsag tries to connect the main factors which influence on the formation of river channels (geomorphologic and geologic features of a territory, hydrologic regime, and alluvial sediments) with channel morphology and vertical channel deformations. He emphasized the importance of geomorphologic features which influence on the formation of river channel profiles, their shape and development.

The Selenga basin zoning was done on the basis of channel-formation activity of rivers. According to such a zoning the territory was divided into three districts: the Upper Selenga district, the Orkhon-Selenga district and the Khantay district. Each district has its own specific conditions of channel-forming determined by effective water discharge and character of inundation of floodplains. In conditions of free development of channel deformations in Upper Selenga and Khantay districts multi-thread channels are widespread due to regular and long-term floodings. In the Orkhon-Selenga district, along with multi-thread channels, meanders forming in both free and adapted conditions are also widespread. These results provide us with understanding of crucial role of channel evolution in matter supply to rivers. At the same time the absence of exact descriptions of channel development is still prevents from a complete assessment of channel erosion contribution to total sediment and dissolved matter fluxes.

Soil erosion

Overgrazing and land-use mismanagement are considered to be main causes of soil erosion and land degradation in the upper Selenga basin rivers. Grassland vegetation has been reported to have decreased recently due to overgrazing by an increasing number of livestock [Chuluun and Ojima, 2001]. In general, the soil in a semiarid area has low organic content and a large percentage of silt portions, which results in a high susceptibility to soil crusting. The decrease in grassland vegetation increases

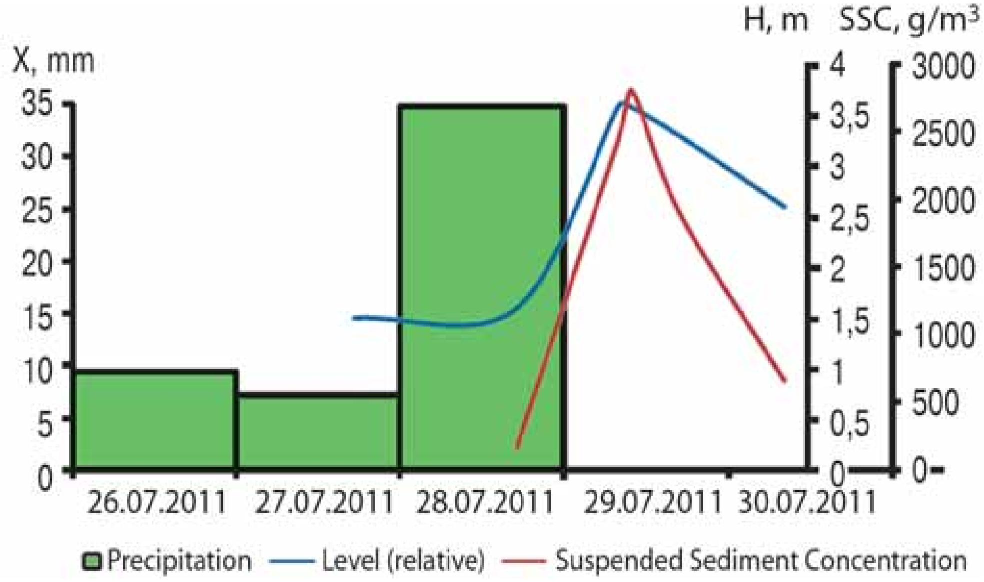

Fig. 4. Water level and SSC change at Orkhon river after period of heavy rainfall (27-07/2011–30-07/2011)

the raindrop impact on the soil surface, splash erosion, and susceptibility to surface sealing, thereby causing enhanced water erosion. Therefore, the surface vegetation cover is considered to be the primary reason for soil erosion [Onda et al., 2006].

Increase of erosion process intensity in the first two-thirds of the 20th century in the Selenga River watershed and a reduction of this intensity in the last third of the century is identified by [Korytny et al., 2003]. Changes in the river network structure (the order of rivers, lengths, etc.) as a result of agricultural activity during the 20th century are regarded to be a driving factor of this increase. The soil erosion rate was observed to be directly proportional to the severity of grazing [Chen et al., 2007].

Exact links between field data available on soil erosion and land degradation processes and matter movement along waterways are limited. Nevertheless some data show evidence that large floods, the rarest of hydrological events, can have the biggest impact, carrying the most sediment and dissolved matter mostly due to surface erosion. Observations made upstream of the Kharkhorin village at the Orkhon river at 29–31 of July demonstrate a significant increase of suspended load due to heavy rains and water level increase (Fig. 4). Our estimates show that the sediment load was about 3000 tons per day, which exceeds the average value for this period 10 times. It should be noted that the upstream reaches of these rivers contain large gold mining areas. Thus, the rates of matter increase could also be affected by mining.

CONCLUSION

Synthesis of recent field campaigns data [Stubblefield et al., 2005; AATA 2008; Baljinnyam et al., 2009; Integrated Water..., 2010], reviews of mid-century observations [Kuznetsov, 1955; Hydrological regime..., 1977] and field works carried out by our team in 2011, provide new evidence from in-situ sampling of rapidly changing characteristics of rivers.

Various types of mining activities appear to provide significant changes in suspended or dissolved load. Open-cast gold mines of Tuul and Orkhon river basin lead to significant increase of SSC and SL. Flooding could breach thin strips of land separating dredge pits from river channels, resulting in massive sediment loading, as it was observed in the studied rivers. Elevated loading of dissolved ions was observed below ore mining and ore processing factory of the Erdenet in the Khangal river. At the same time low water discharge of the Khangal river provide fast decrease of dissolved solids concentration downstream along river network (below Khangal river confluence with large Orkon river). Observed increase of dissolved solid load along mining zone could be compared with total water-borne mass flow of metals to surface waters in England and Wales (which is 1509 kg/day for Fe, 13.9 kg/day for Mn and 50.6 kg/day for Pb) [Mayes et al. 2010].

Mass flows in the Upper Selenga river basin are somewhat different from both suspended (SSC) and dissolved solids concentration measurements. For instance, mass flows of Fe were increasing below Zaamar goldfield and downstream at a much higher rate than concentrations do. This is due to incorporation of local discharges with local concentrations and discharges increase considerably at downstream locations of the river system. Mass flows are relatively low at the mining site, but can increase by orders of magnitudes directly after the site indicating a significant impact from the mining activities.

More generally a main result is that while both suspended and dissolved material is provided from different sources, the total annual mass flow mostly depends on specific hydrological events. Large floods can have the biggest impact, carrying the most sediment from the surface – both from mined and non-mined lands, and reworking channel and floodplain geometry. 137Cs inventory for un-mined basins showed [Onda et al., 2006] that that the high sediment yields in the former case might be due to the susceptibility to erosion by recent over grazing. Industry accelerates both watershed and channel erosion and thus increases contributions from all sources. Further understanding of sources contribution, as far as understanding of sediment and dissolved matter regional budget could be done on joining large-scaled and small-scaled observations.

Potentially important questions that have not been addressed include effects of sediment and dissolved matter fluxes in ground waters. Wastewaters in the area of mining and industrial centers can cause serious alterations in groundwater recharge. Since groundwater is the main drinking water source in the region [AATA, 2008] and pollution of aquifers is often irreversible due to very slow recharge rates [Zandaryaa et al. 2008] – the process should thus be controlled.

Overall, to increase the knowledge about sediment and dissolved matter fluxes spreading and long term effects in this region, hydrological measurement and monitoring need to be extended. Simultaneous monitoring of both discharges and concentrations is essential for the reliability of mass flow estimations. If such extensive monitoring would be implemented, this would considerably decrease uncertainties in future (mass flow) investigations. Addressing of individual (and combined) effects of multiple upstream matter source zones on downstream mass flows would be of great value, from both scientific and pollution management perspectives.

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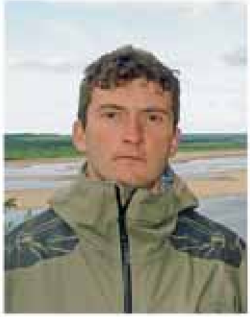

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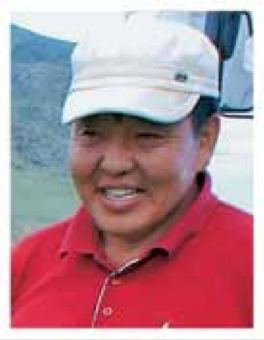

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