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# Modelling suspended sediment distribution in the Selenga River Delta using LandSat data

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**Abstract.** The Selenga River is the largest tributary of Baikal Lake and it's delta covers around 600 km$^2$. Suspended sediment concentrations (SSC) in the Selenga river delta were modelled based on LandSat images data. The seasonal variability in suspended sediment retention during the period 1989 to 2015 was calculated. The results suggest that sediment storage in the Selenga delta is observed during high discharges ($>1500\,\mathrm{m^3\,s^{-1}}$), whereas sediment export increases under lower flow conditions ($<1500\,\mathrm{m^3\,s^{-1}}$). The changes in seasonal SSC patterns are explained by wetland inundation during floods and channel erosion or Baikal wind surge during low flow periods.

## 1 Introduction

River mouths are important areas of sediment and chemical transport at the continental scale. They are recognized as an important lateral geochemical barrier where, over 90 % of suspended and 40 % of dissolved carbon associated with global geochemical fluxes is trapped (Lisitzyn, 1994). Sediment retention is most significant within deltas where, due to bifurcation and the existence of abundant wetlands, large volumes of sediment are stored. Deltas with complex channel networks can efficiently distribute and store sediment inputs along their channels and within floodplain environments (Syvitski et al., 2005, 2012; Rowland et al., 2009).

One of the most ancient and largest freshwater deltas in the World – the Selenga River Delta – is located at the mouth of the main tributary of the world's largest freshwater lake by volume (Lake Baikal). Due to the absence of detailed long-term and seasonal discharge and sediment monitoring, only a few studies (e.g. Potemkina, 2004) have examined sediment retention in this region. As a result, assessing the impacts of observed changes in the levels of Lake Baikal, the Selenga River water regime and sediment loads (Chalov et al., 2013, 2015) on the distribution of SSC in the Selenga River delta requires implementation of a modelling approach to provide a long-term insight into sediment and associated contaminant delivery to Lake Baikal.

## 2 Materials and methods

### 2.1 Site description

The Selenga River's 447.06 km$^2$ drainage basin comprises 82 % of Lake Baikal basin (Garmaev and Khristoforov, 2010). Located in the south-east end of Baikal Lake, the Selenga River delta constitutes the largest (600 km$^2$) wetland region in East Siberia. The Selenga River delta consists of three main distributary sectors: Lobanovskiy channel system (right, III), the Sredneustievskiy channel system (central, II), and the Selenginskiy channel system (left, I), named after the largest channels of the dispersal system (Iliycheva et al., 2015) (Fig. 1). A huge part of the delta is covered with a great number of different sized lakes. Altogether, the Selenga River Delta comprises more than 30 distributaries.

According to records from the Mostovoy gauging station (located 127 km from the delta mouth, observation period – since 1934), the average annual runoff of the Selenga is 29.3 km$^3$ year$^{-1}$. Over the period 1934–2015, the maximum observed discharge was 6420 m$^3$ s$^{-1}$ (11 August 1993) and the minimum 29.9 m$^3$ s$^{-1}$ (9 March 2012). The average discharges are highest during the spring-summer period with the peaks typically up to 5000–7000 m$^3$ s$^{-1}$.

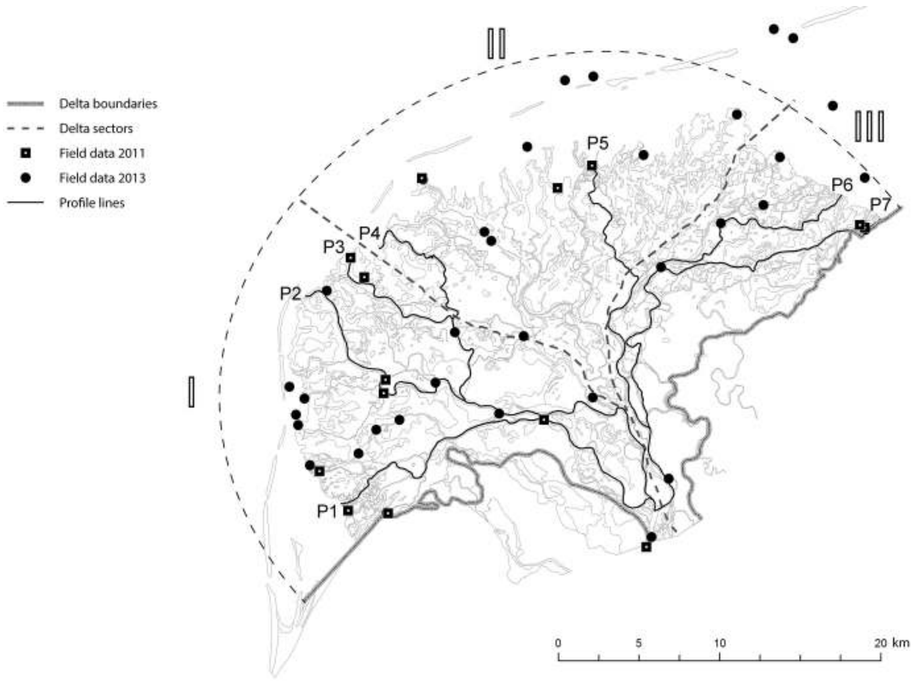

**Figure 1.** Selenga River delta ($P1$–$P7$ – distributaries used for $\Delta S$ calculations; I, II, III – Selenga Delta sectors; dots represent the locations of in-situ SSC measurements).

## 2.2 Suspended sediment concentration model based on LandSat data

This study was based on available hydrological (field campaigns with SSC measurements in 2011 and 2013) and remote sensing (82 Landsat images for the period 1989–2015) data. Field measurements of SSC for calibration of the SSC model were undertaken at more than 50 locations within the delta (Chalov et al., 2016) (Fig. 1). The available dataset was used for statistical analyses to generate least squares regression models for predicting surface SSC as a function of surface reflectance (Curran and Novo, 1988). The model relies on comparison of satellite images (raw pixel values, so called DN – digital numbers) with the SSC data obtained during field campaigns in 2011 and 2013. 2011 field measured data were compared with Landsat 5 image (17 August 2011), yielding:

$$\mathrm{SSC} = 2.418\,\mathrm{DN} - 29.91 \tag{1}$$

2013 data were compared with the Landsat 8 image (23 July 2013), yielding:

$$\mathrm{SSC} = 0.015\,\mathrm{DN} - 94.77 \tag{2}$$

The regression models (1, 2) were further applied to 82 Landsat 5 and Landsat 8 images with a spatial resolution of 30 m. The image processing approach was basically related to the calculation of SSC values ($\mathrm{mg\,L^{-1}}$) for all image pixels. An atmospheric correction method, called the "dark object method" was used for processing Landsat images. This method is based on selection of one constantly dark object on the reference image and applying the pixel value of this object to calibrate all the images in the series (Chavez, 1996). In case of the research reported here, the "dark object" was the deep part of Baikal lake. Reference images, which were used for correction comprised Landsat 5 (17 August 2011) and Landsat 8 (23 July 2013).

Since the delta consists of more than 30 branches and channels, 7 representative distributaries were selected for calculation of longitudinal change in SSC (Fig. 1). Distributaries P1, P2, P3 are located within the left channel system, P4, P5 – the central channel system, and P6, P7 – the right channel system.

The SSC balance was calculated for each distributary on the basis of the difference between SSC at the upstream ($S_1$) and downstream ($S_2$) ends:

$$\Delta S_0 = S_2 - S_1 \tag{3}$$

Values for $S_1$ and $S_2$ were estimated as an average for every 500 m of each distributary. Relative sediment retention (%) was calculated as:

$$\Delta S = \Delta S_0 / S_1 \tag{4}$$

Average $\Delta S$ values for each sector were revealed from comparison of the discharges in the upper part of the delta (Mostovoi gauging station data) ($Q_o$) and discharge in each channel sector ($Q_i$). Since there is no constantly measured discharge data in each channel system, average values for

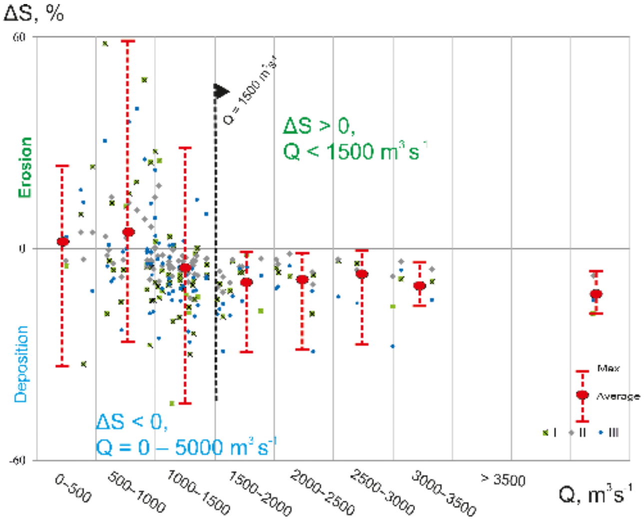

**Figure 2.** Suspended sediment retention (%) changes within the Selenga delta under different discharge ($Q$) conditions (I, II, III – delta sectors according to Fig. 1).

water partitioning between sectors (Chalov et al., 2016) were used. Three possible ratios between sediment input and output were analysed: $S_2 > S_1$, $S_2 < S_1$ and $S_2 \approx S_1$, which correspond to either erosional ($\Delta S > 0$), depositional ($\Delta S < 0$) or equilibrium ($\Delta S = 0$) states.

## 3 Results and discussion

Relative sediment retention ($\Delta S$) estimates suggest that 33 % of the suspended sediment load is stored within the delta (Fig. 2). SSC $\Delta S$ is controlled by discharge. Longitudinal increases in SSC were observed only during low-water periods (discharges less than 1500 $\mathrm{m^3\,s^{-1}}$). In most cases, relative values of sediment retention ($\Delta S$, %) were higher in the left or right delta sectors than in the central delta sector. Average sediment retention over 82 observational patterns was estimated at 6 % in the Left sector (I), 3 % in the Central (II) and 6 % in the Right (III) sectors. The highest deposition rate was observed in the Left delta sector ($\Delta S = 58\,\%$, when $Q_o = 575\,\mathrm{m\,s^{-1}}$). In the other delta sectors, the highest deposition rate was 17 % (II) and 39 % (III).

The observed seasonal variability of $\Delta S$ could be explained by hydrological and hydraulic factors. Longitudinal decline ($\Delta S < 0$) in water surface slopes along the delta and the corresponding order of magnitude decrease in transport capacity causes in-channel sediment storage. This is also related to the coarser bottom sediments observed in the upper part of the delta (Ilycheva et al., 2015). In addition to within channel storage, an important role in sediment retention is also played by floodplain inundation. Higher water levels increase connectivity between various delta wetlands and distributaries which causes the inundation of plants along the delta. This, in turn, causes storage of sediment on the floodplain surface and in oxbow lakes, marshes, etc. Over 50 wetland systems can be found in the lower part of the delta, during the high-discharge period, which cause significant (up to 90 %) declines in SSC along the channel systems.

The increase in sediment concentrations ($\Delta S > 0$) during the low water period is caused by the role of in-channel erosion as a component of sediment mobilization. The downstream parts of most of the delta distributaries represent actively eroded channels with high rates of bank retreat (up to 10 m) (Iliycheva et al., 2015). The probable explanation for this channel degradation which might impact on the sediment budget when the sediment delivery is relatively low (dry seasons) is that the transport capacity changes along bifurcational nodes. Under bankfull discharges, bifurcation might lead to the increase of total transport capacity of the river flow calculated as a sum of separate channels along braided (distributary) reachesd (Chalov and Alexeevsky, 2015). On the other hand, a decline in water velocity when the discharge inundates the floodplain surfaces, means that transport capacity is likely to have an opposing trend during high water periods. Another factor influencing the increase in suspended sediment transport in the lower part of the delta is the Baikal wind surge which may deliver significant amounts of sediment from Baikal into the Selenga River and then cause $\Delta S > 0$ responses.

Our preliminary results indicate hydrological drivers for the suspended sediment budget in the large distributary delta. The relationships between discharge and sediment retention rates ($\Delta S$) could be used for predicting future delta responses. The latter is particularly important in the context of the rapid development of the Selenga River (e.g. a few dams are under construction in the Mongolian part of the catchment) which will cause changes in the hydrological regime of the delta in the near future.

## 4 Data availability

Underlying research data includes daily discharge from Russian HydroMet Service (accessed from AIS GMVO centre gmvo.skniivh.ru) and field data for Selenga delta (available at Supplement of Chalov et al., 2016 – see references). The 70 LandSat images were accesses from U.S. Department of the Interior U.S. Geological Survey at earthexplorer.usgs.gov.

**Competing interests.** The authors declare that they have no conflict of interest.

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