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Source identification of fine-grained suspended sediment in the Kharaa River basin, northern Mongolia

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HIGHLIGHTS

- Applied statistical approach for selecting composite fingerprints in Mongolia.
- Geochemical fingerprinting for the definition of source areas in semiarid catchment.
- Test of applicability of sediment sourcing in large scale semi-arid catchments.
- Combined geochemical and fallout radionuclide fingerprint for management advice.

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ABSTRACT

Fine sediment inputs into river systems can be a major source of nutrients and heavy metals and have a strong impact on water quality and ecosystem functions of rivers and lakes, including those in semiarid regions. However, little is known to date about the spatial distribution of sediment sources in most large scale river basins in Central Asia. Accordingly, a sediment source fingerprinting technique was used to assess the spatial sources of fine-grained (<10 μm) sediment in the 15 000 km^2 Kharaa River basin in northern Mongolia. Variation in geochemical composition (e.g. in Ti, Sn, Mo, Mn, As, Sr, B, U, Ca and Sb) was used for sediment source discrimination with geochemical composite fingerprints based on Genetic Algorithm (GA)-driven Discriminant Function Analysis, the Kruskal–Wallis H-test and Principal Component Analysis. All composite fingerprints yielded a satisfactory GOF (>0.97) and were subsequently used for numerical mass balance modelling with uncertainty analysis. The contributions of the individual sub-catchment spatial sediment sources varied from 6.4% (the headwater sub-catchment of Sugnugur Gol) to 36.2% (the Kharaa II sub-catchment in the middle reaches of the study basin), generally showing higher contributions from the sub-catchments in the middle, rather than the upstream, portions of the study area. The importance of river bank erosion is shown to increase from upstream to midstream tributaries. The source tracing procedure provides results in reasonable accordance with previous findings in the study region and demonstrates the applicability and associated uncertainties of the approach for fine-grained sediment source investigation in large scale semi-arid catchments.

1. Introduction

Enhanced mobilisation and delivery of fine-grained (<63 μm) sediment as a result of soil erosion can have a detrimental impact on water quality in rivers and lakes (Quinn and Stroud, 2002; Matthaei et al., 2010; Bilotta and Brazier, 2008; Rode et al., 2010; Collins et al., 2011). Fine sediment intrusion has also been identified as a major factor contributing to significant benthic ecosystem alterations, affecting aquatic biota such as fish and macro-invertebrates through congestion of the hyporheic interstices (Wood and Armitage, 1997; Collins et al., 2011; Kemp et al., 2011; Jones et al., 2012; Hartwig et al., 2012). Against this background a reliable understanding of the contributing sources and delivery pathways of fine-grained sediment into freshwater systems is of pivotal importance for sustainable River Basin Management Planning (RBMP) (Collins et al., 2011).

Whereas the investigation of fine-grained sediment sources in small catchments can rely on intensive measurement and monitoring procedures like erosion plot experiments, the use of profilometers or erosion pins (Collins and Walling, 2004), these techniques are impractical in large-scale catchments and become increasingly labour and resource intensive with catchment size. Equally, the information collected using erosion monitoring techniques needs to be converted into sediment source data on the basis of synthesis with additional lines of evidence including sediment transport and delivery pathways and ratios

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(Collins and Walling, 2004). The investigation of sediment sources in large-scale catchments has therefore frequently relied on indirect and remote investigation techniques. Remotely sensed data and information on soil, land use and climatic properties can be used to assess surface erosion. Universal Soil Loss Equation (USLE) calculations that include precipitation and topographic information have been used to delineate areas with high erosion risk (Jain and Kothyari, 2000; Lu et al., 2003). Alternatively, Theuring et al. (2013) estimated soil erosion, sediment transport and the sediment budget for the River Kharaa catchment, Mongolia, with the sediment budget model SedNet (Wilkinson et al., 2004). But, whereas these techniques help to assemble information on the potential for sediment inputs to streams from hillslope erosion, the sediment fluxes from river basins typically represent inputs from a variety of sources in addition to hillslopes, including eroding channel banks and road networks (De Rose and Basher, 2011; Wilkinson et al., 2005; Collins et al., 2010a).

A reliable approach to distinguishing the contribution of suspended sediment from different erosion processes in large scale catchments is the use of atmospheric fallout radionuclide (FRN) tracing techniques to estimate the proportion of surface eroded sediments, bank eroded sediments and sediments from other sources such as gullies (Zapata, 2002). By utilizing Be-7, Cs-137 and Pb-210, Theuring et al. (2013) have demonstrated that 13% and 54%, respectively, of the sampled suspended sediment originate from surface eroded sources in the Kharaa catchment, Mongolia. Spatial variations in these sediment source contributions depend on the location within the catchment (headwaters or downstream sections) and the principal causes of runoff generation (summer rainfall or snowmelt). The remaining sampled suspended sediment originates largely from river bank erosion and in some sub-catchment areas from gully erosion. The main challenge for understanding, quantifying and modelling catchment-scale fine-grained sediment budgets, especially in developing countries, is the lack of information on sediment origin, mobilisation and transfer dynamics through the fluvial system (Collins et al., 2001; Walling et al., 2001).

Sediment source fingerprinting techniques have been increasingly used to assess the proportional contribution of erosion sources and to spatially delineate source areas in river catchments of varying scales and geographical locations (Owens et al., 1999; Bottrill et al., 2000; Owens et al., 2000; Russell et al., 2001; Collins and Walling, 2002; Carter et al., 2003; Motha et al., 2004; Walling et al., 2006, 2008; Foster et al., 2007; Minella et al., 2008; Hatfield et al., 2008; Hughes et al., 2009; Bird et al., 2010; Collins et al., 2013a,b). A review of the techniques and applications of sediment source fingerprinting techniques can be found for example in Walling (2005), Davis and Fox (2009)

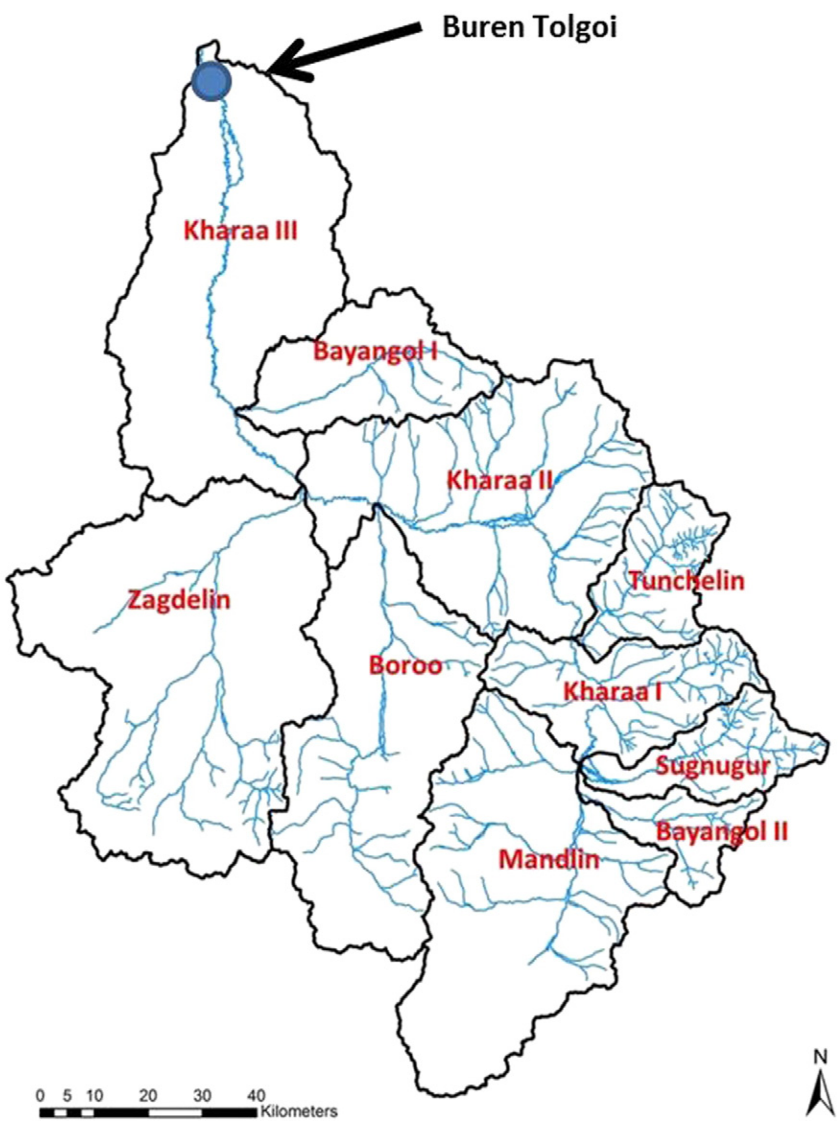

Fig. 1. The channel network of the Kharaa River study basin, showing the sub-catchments used in the spatial sediment sourcing programme.