Temporal variation in suspended sediment transport and processes

Variation temporelle du transport des sédiments en suspension et des processus

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RÉSUMÉ

La dynamique naturelle du transport des sédiments en suspension a été perturbée dans la plupart des cours d'eau par l'intervention humaine directe dans les chenaux et l'altération des surfaces terrestres dans les bassins versants. Des solutions de gestion sont nécessaires pour minimiser leur impact sur les systèmes fluviaux, mais pour ce faire, il faut disposer d'informations fiables sur les sources de sédiments en suspension dans les rivières. Dans cette étude, des empreintes sédimentaires spectrales ont été réalisées sur des échantillons de sédiments en suspension prélevés lors d'événements de haut débit dans la rivière Aire afin d'étudier si et comment les variations de sources de sédiments contrôlent les concentrations de sédiments en suspension. Un total de 200 échantillons de sédiments en suspension ont été collectés pendant 14 événements de haut débit entre 2015 et 2017 et comparés aux sources potentielles de sédiments dans le bassin versant : sols de prairies dans trois zones lithologiques, érosion des berges et poussières des routes urbaines. Les résultats indiquent que les sources dominantes de sédiments en suspension dans la rivière Aire proviennent de la géologie du calcaire et des poussières des routes urbaines, mais des variations significatives dans les contributions des sources pendant et entre les événements ont été observées. Bien que les concentrations de sédiments aient généralement été influencées par l'hydrologie, la connectivité des sédiments en combinaison avec les conditions d'humidité antécédentes semble également être importante pour contrôler l'approvisionnement de sédiments.

ABSTRACT

Natural suspended sediment transport dynamics have been perturbed in most rivers by direct human intervention in channels and alteration to land surfaces in the catchments. Management solutions are needed to minimize their impact on river systems, but, to do this, reliable information is needed on the sources of suspended sediment in rivers. In this study, spectral-based sediment fingerprinting was conducted on suspended sediment samples collected during high flow events in the River Aire to investigate if and how variations in sediment sources control suspended sediment concentrations. A total of 200 suspended sediment samples was collected during 14 high-flow events between 2015 and 2017, and compared against potential sediment sources in the catchment: grassland topsoil in three lithological areas (limestone, millstone grit and coal measures), eroding riverbanks, and urban street dust. The results indicate that the dominant sources of suspended sediment in the River Aire is from limestone geology and urban street dust, but significant variations in source contributions during and between events were observed. While sediment concentrations were generally hydrologically driven, catchment sediment connectivity in combination with antecedent moisture conditions also appear to be important in controlling the supply of sediment.

KEYWORDS

Catchment sediment connectivity, DRIFTS, sediment fingerprinting, soil erosion

1 INTRODUCTION

This study investigated the role of hydro-meteorological and catchment processes in driving temporal variations in the sources and concentrations of suspended sediment (SS) in rivers during individual high-flow events. The specific objective were to (i) investigate the behaviour of SS source variations during hysteresis patterns; (ii) identify source-specific hydro-meteorological controlling factors; and (iii) estimate source-specific sediment loads based on these hydro-meteorological factors.

2 MATERIALS AND METHODS

The study was conducted on the River Aire, a large catchment located in northern England (catchment area: 690 km^2). The catchment is covered primarily by grasslands (59% cover), particularly in the upper catchment, with large urban areas (25%) and scattered arable land (4%) located in the middle and lower catchment. The upper catchment forms part of the Yorkshire Dales National Park where land cover is predominantly moorland (12% cover).

2.1 Data collection

SS samples were collected from the River Aire in the City of Leeds during high discharge events between June 2015 and March 2017 using a depth-integrating sampler. A total of 14 high-flow events were sampled, resulting in 200 individual SS samples collected over the flood hydrographs. Sediment source samples were collected from the catchment based on five potential sediment source types: limestone, millstone grit and coal measures geology; eroding riverbanks; and urban street dust. A total of 117 sediment sources samples were collected from across the catchment

High frequency (15-min) river discharge data were obtained from the closest Environment Agency gauging station to the SS sampling location. Precipitation data were obtained for one location in each of the three main geological zones.

2.2 Sediment fingerprinting and data analysis

SS source samples were prepared by wet sieving to retain the < 63 µm fraction of the sediment to limit the effect of particle size on spectral distortion and source apportionment (Poulenard et al., 2009; Laceby et al., 2017). The sediment source, BS, and SS samples were filtered on quartz fibre filters and oven-dried for two hours at 105˚C (Cooper et al., 2014; Pulley et al., 2015). All samples were measured directly on the filters with DRIFTS (Cooper et al., 2014; Poulenard et al., 2009). Samples were scanned at a 4 cm^{-1} resolution across the 4000-400 cm^{-1} spectrum with 32 co-added scans per spectrum. Only the ranges 3800–2400 cm^{-1} and 2300–650 cm^{-1} were used for further analysis to avoid interference of CO2 absorption (Poulenard et al., 2009).

Source DRIFTS spectra were evaluated statistically using principal component analysis and discriminant analysis based on Mahalanobis Distances to determine if sources could be discriminated. An unmixing model was developed based on a set of 54 experimental mixtures using Partial Least Squares Regressions (PLSR, Poulenard et al., 2009). The relationship between hydro-meteorological variables and total and source-specific SSCs was investigated statistically using PLSR.

3 RESULTS AND DISCUSSION

The dominant sediment sources during the in the River Aire appeared to be limestone-grassland (45% ± 12%), followed by urban street dust (43% ± 10%). Millstone- and coals-grassland contributed on average 19% (± 13%) and 14% (±10%) respectively, while eroding riverbanks accounted for 16% (± 18%) of the total SSC.

Seasonal variation in the dominant sediment sources was observed. The relative urban street dust contribution was highest in summer (68% ± 10%) and lowest in autumn (35% ± 10%), while the riverbank contribution was lowest in summer (11% ± 18%). In autumn and winter, all sources were more equally represented compared to spring and summer.

Furthermore, variation in SS during and between high-flow events was also apparent. For example during multiple discharge peaks in November 2016 and February 2017 (Fig. 1). The dominant source of SS was from grassland on limestone geology in early November, but became decreasingly important over the 10 days, while the signal from coal measures increased (Fig 1a). Similar trends in SSCL, SSCC and SSCR were evident in discharge peaks in February 2017, while the total SSC appeared to decrease despite similar discharge peaks (Fig 1b). Sources also varied over individual events with quickly responding contributions from urban sources that decreased over the flood hydrograph.

The PLSR analysis of the relationship between hydro-meteorological variables and SSCs identified different explanatory variables for the total and source-specific. For total SSC, precipitation 1 day before the sample collection and discharge during the sampling best explained SSC, whilst earlier precipitation was more important for sources located further from the sampling location.

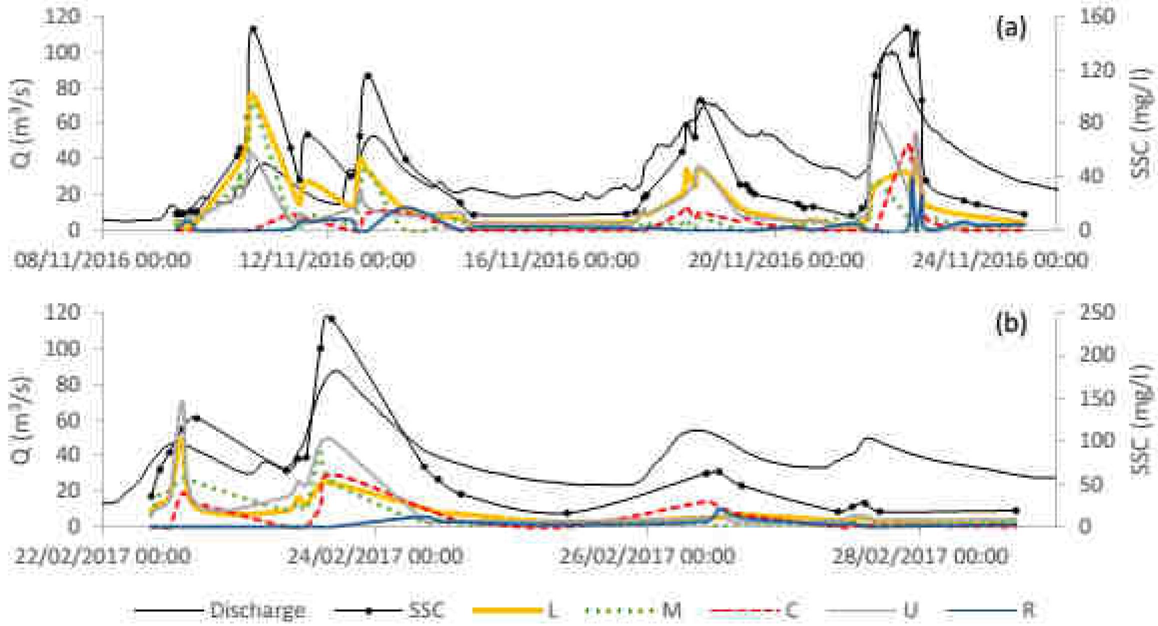

Figure 1: Discharge (Q) and sampled suspended sediment concentration (SSC) with estimated sediment source-specific SSCs in (a) November 2016 and (b) February 2017. (Sediment sources: grassland from the limestone (L), Millstone grit (M), coals measures (C) areas, riverbanks (R), and urban street dust (U)).

4 CONCLUSIONS

The findings in this study show that the combination of innovative statistical methods for sediment source apportionment and the estimation of suspended sediment concentrations provide opportunities to identify underlying processes for temporal variation in suspended sediment transport, which can serve as a basis for process-based modelling and management decisions.

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