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The influence of contrasting suspended particulate matter transport regimes on the bias and precision of flux estimates

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Abstract

A large database (507 station-years) of daily suspended particulate matter (SPM) concentration and discharge data from 36 stations on river basins ranging from 600 km^2 to 600,000 km^2 in size (USA and Europe) was collected to assess the effects of SPM transport regime on bias and imprecision of flux estimates when using infrequent surveys and the discharge-weighted mean concentration method. By extracting individual SPM concentrations and corresponding discharge values from the database, sampling frequencies from 12 to 200 per year were simulated using Monte Carlo techniques. The resulting estimates of yearly SPM fluxes were compared to reference fluxes derived from the complete database. For each station and given frequency, bias was measured by the median of relative errors between estimated and reference fluxes, and imprecision by the difference between the upper and lower deciles of relative errors. Results show that the SPM transport regime of rivers affects the bias and imprecision of fluxes estimated by the discharge-weighted mean concentration method for given sampling frequencies (e.g. weekly, bimonthly, monthly). The percentage of annual SPM flux discharged in 2% of time (Ms_2) is a robust indicator of SPM transport regime directly related to bias and imprecision. These errors are linked to the Ms_2 indicator for various sampling frequencies within a specific nomograph. For instance, based on a deviation of simulated flux estimates from reference fluxes lower than ±20% and a bias lower than 1% or 2%, the required sampling intervals are less than 3 days for rivers with Ms_2 greater than 40% (basin size < 10,000 km^2), between 3 and 5 days for rivers with Ms_2 between 30 and 40% (basin size between 10,000 and 50,000 km^2), between 5 and 12 days for Ms_2 from 20% to 30% (basin size between 50,000 and 200,000 km^2), 12–20 days for Ms_2 in the 15–20% range (basin size between 200,000 and 500,000 km^2).

Keywords: Suspended particulate matter; Load estimate; Flux; Accuracy; Precision; Sampling frequency

1. Introduction

Many authors have observed that daily river suspended particulate matter (SPM) concentration (Cs) and specific fluxes (*Y*) present enormous time and space variations due to runoff (*q*) and Cs vs. *q* relationships

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(Williams, 1989), which occur as a result of the interaction of many factors, mainly climate, geology (including soil type), relief, land use (including vegetation) and anthropogenic factors (Meade and Parker, 1985; Milliman and Syvistski, 1992; Walling and Webb, 1996). Land denudation assessments and the related global sediment fluxes to oceans are mainly computed from interannual SPM fluxes and yields (Y*); they show a wide range (Y* from less than 10 to more than 10,000 t km^{-2} year^{-1}) (Milliman and Meade, 1983; Milliman and Syvistski, 1992; Ludwig and Probst, 1998). A preliminary assessment of current trends in the annual sediment loads and runoff of 145 major rivers of the world has recently been made from long-term records (>25 years) (Walling and Fang, 2003). It indicates that approximately 50% of sediment load records show evidence of statistically significant upward or downward trends, with the majority showing declining loads. Reservoir construction probably has the greatest influence on land–ocean sediment fluxes, but the influence of other factors resulting in increasing sediment load is not clear (Syvitski et al., 2005). Walling and Fang (2003) pointed out the difficulty of assembling such a database due to the lack of reliable sediment monitoring programmes in many areas of the world.

Global variability of daily SPM fluxes and their driving factors are also very difficult to address, mostly due to lack of representative databases assembled on a global scale (Meybeck et al., 2003), although there are a few national sediment monitoring programmes in the former USSR, the USA, China and Germany, and regional studies such as the UK Land–Ocean Interaction Study (LOIS) (Wilkinson et al., 1997; Philipps et al., 1999). Temporal variations of daily sediment fluxes at a given station cover an enormous range, commonly over 4–5 orders of magnitude (Syvitski and Morehead, 1999; Meybeck et al., 2003). The distribution of daily SPM fluxes is highly skewed: most sediment load is carried to oceans over a short period of time. The most variable fluxes are observed in river basins combining several erosivity factors, such as very high runoff during floods, steep relief, and occurrence of erodible materials.

River SPM is also an important carrier of organic carbon, nutrients, metals and persistent organic pollutants, and is often used to quantify their transport from land to ocean. The SPM concentration per litre of water is also a traditional indicator of water quality for many users. River SPM fluxes are therefore often requested in international surveys, at cross-border river stations and for shared water bodies (lakes, regional seas).

In many part of the world, evaluations of annual suspended sediment load are based on water quality monitoring programmes involving infrequent sampling. When using this type of data, the concentrations are either considered as constant around the sample or are reconstituted on the basis of continuous water discharge (Q) records and of SPM vs. Q relationships (rating curves). The reliability of load estimates by these methods in the context of sampling strategies have long been the subject of much discussion and controversy (Ongley et al., 1977; Walling and Webb, 1981, 1985; Thomas, 1985; Richards and Holloway, 1987; Olive and Rieger, 1988; Ferguson, 1986, 1987; De Vries and Klavers, 1994; Littelwood, 1995; Littlewood et al., 1998; Philipps et al., 1999; Holtschlag, 2001; Coynel et al., 2004). Two types of error characterizing each specific SPM sampling strategy (Walling and Webb, 1981) are commonly defined: bias (or systematic error) and imprecision (degree of dispersion). They are used to (i) assess the potential reliability of loads calculated using various procedures, (ii) demonstrate the influence of sampling strategies on flux reliability, or (iii) optimize sampling frequency or strategies (regular or stratified discharge-based) for a given precision target.

Only a few studies have compared the performance of suspended sediment load estimates from these infrequent samplings for rivers with contrasting characteristics (Ongley et al., 1977; Richards and Holloway, 1987; Philipps et al., 1999; Coynel et al., 2004). Philipps et al. (1999) applied 22 algorithms of load estimation to two rivers in the LOIS study area (3 monitoring stations, range of basins 500–3315 km^2): their results exhibited a number of consistent differences, related to the contrasting water discharge and suspended sediment transport regimes for rivers of different sizes. Basin size was found to be related to both the accuracy and precision of the individual load estimation procedures, with the performance of both measures declining with reduction in drainage area.

In this paper, a large database (507 station-years) of daily SPM concentration and discharge data was assembled, including rivers with contrasting SPM flux regimes from two continents (36 stations on river basins ranging from 600 km^2 to 600,000 km^2 in USA and Europe) in order to:

1. evaluate and compare errors (bias and imprecision) of annual SPM fluxes when using infrequent surveys;
2. test the possibility of linking these errors to indicators of daily sediment transport regime, such as those based on flux duration curves (Meybeck et al., 2003).

For simplicity, we took the discharge-weighted mean concentration method most commonly used by the scientific community and environmental management