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Sediment yield in Africa

Matthias Vanmaercke [a,b,*], Jean Poesen [a], Jente Broeckx [a], Jan Nyssen [c]

[a] Division of Geography, Department of Earth and Environmental Sciences, KU Leuven, Heverlee, Belgium
[b] Research Foundation Flanders (FWO), Brussels, Belgium
[c] Department of Geography, Ghent University, Ghent, Belgium

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ABSTRACT

Several studies have compiled and analysed measured contemporary catchment sediment yield (SY, [t km^{-2} y^{-1}]) values for various regions of the world. Although this has significantly contributed to our understanding of SY, Africa remains severely underrepresented in these studies. The objective of this article is therefore: (1) to review and compile available SY data for Africa; (2) to explore the spatial variability of these SY data; and (3) to examine which environmental factors explain this spatial variability.

A literature review resulted in a dataset of SY measurements for 682 African catchments from 84 publications and reports, representing more than 8340 catchment-years of observations. These catchments span eight orders of magnitude in size and are relatively well spread across the continent. A description of this dataset and comparison with other SY datasets in terms of spatial and temporal distribution and measurement quality is provided. SY values vary between 0.2 and 15,699 t km^{-2} y^{-1} (median: 160 t km^{-2} y^{-1}, average: 634 t km^{-2} y^{-1}). The highest SY values occur in the Atlas region with SY values frequently exceeding 1000 t km^{-2} y^{-1}. Also the Rift region is generally characterised by relatively high SY values, while rivers in Western and Central Africa have generally low SY values.

Spatial variation in SY at the continental scale is mainly explained by differences in seismic activity, topography, vegetation cover and annual runoff depth. Other factors such as lithology, catchment area or reservoir impacts showed less clear correlations. The results of these analyses are discussed and compared with findings from other studies. Based on our results, we propose a simple regression model to simulate SY in Africa. Although this model has a relatively low predictive accuracy (40%), it simulates the overall patterns of the observed SY values well. Potential explanations for the unexplained variance are discussed and suggestions for further research that may contribute to a better understanding of SY in Africa are made.

Contents

* Corresponding author at: Division of Geography, Celestijnenlaan 200e - box 2409, 3001 Heverlee, Belgium.
E-mail address: Matthias.Vanmaercke@ees.kuleuven.be (M. Vanmaercke).

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1. Introduction

Understanding the factors and processes controlling contemporary catchment sediment yield (SY, [t km^{-2} y^{-1}]; i.e. the mass of sediment annually leaving a catchment per unit of catchment area) is crucial for our comprehension of global denudation rates, biogeochemical cycles, fluvial sedimentary archives and human impacts on sediment fluxes (e.g. Meybeck, 2003; Walling, 2006; Syvitski and Milliman, 2007). Several studies therefore compiled and analysed worldwide SY observations (e.g. Jansen and Painter, 1974; Walling and Kleo, 1979; Dedkov and Mozzherin, 1984; Jansson, 1988; Milliman et al., 1995; FAO, 2008; Milliman and Farnsworth, 2011). Despite its size and physiographic variability (Goudie et al., 1996), Africa is clearly underrepresented in these compilations (Table 1). So far, the FAO (2008) conducted the largest SY data compilation for Africa (Table 1). However, almost half of the 205 African SY observations in this dataset are located in Algeria, Morocco or Lesotho while most other African countries are not or poorly represented (FAO, 2008). Moreover, the few African SY data included in these compilations are mainly for larger river systems (>10,000 km^2). Smaller catchments (<100 km^2) are even more underrepresented (Table 1).

The main reason for this under representation is the limited number of African SY observations available. This was already highlighted by Walling (1984). Nonetheless, a large number of SY measurements have been conducted in Africa but were often only published in internal reports, theses, conference proceedings or local research journals. This is illustrated by a few regional or country-wide SY compilations in Africa (e.g. Rooseboom, 1978; Dunne, 1979; Nyssen et al., 2004; Liénou et al., 2005; Balthazar et al., 2012). Whereas these compilation studies are an important step forward, a comprehensive continent-wide compilation of African SY data is currently lacking. As a result, our insight into the spatial patterns of SY in Africa is limited (e.g. Walling and Webb, 1983; Walling, 1984; Milliman and Farnsworth, 2011).

Also our ability to predict SY of African rivers is hampered by this lack of data. Some models have been proposed to predict SY for specific African regions, but they are mostly based on a relatively limited number of catchments and involve large uncertainties when applied to catchments in other regions (e.g. Picouet et al., 2001; Ning Ma, 2006; Haregeweyn et al., 2008; Meshesha et al., 2011; Schmengler, 2011; Balthazar et al., 2012). Furthermore, these studies focus on only a few specific African regions (e.g. the Ethiopian Highlands; Haregeweyn et al., 2008; Meshesha et al., 2011; Balthazar et al., 2012). Also earlier developed SY models remain poorly tested for African conditions, while studies aiming to apply existing SY models to African catchments often report poor model performances and/or high data requirements (e.g. Bouraoui et al., 2005; Syvitski and Milliman, 2007; Balthazar et al., 2012; Bossa et al., 2012; Pelletier, 2012; de Vente et al., 2013).

It is generally accepted that SY is influenced by catchment area, lithology, topography, land cover, reservoir impacts and climatic conditions (e.g. de Vente and Poesen, 2005; Syvitski and Milliman, 2007; Pelletier, 2012). However, the relative importance of these factors in explaining spatial variation in SY is not fully understood as this also depends on the catchments considered. This issue has been raised before and is evident from the fact that different studies often report different factors controlling SY (e.g. Jansen and Painter, 1974; Walling, 1983; Lane et al., 1997; de Vente et al., 2005, 2006; Syvitski and Milliman, 2007; Haregeweyn et al., 2008; de Vente et al., 2013). Most studies dealing with factors controlling SY focus either on large river basins worldwide (e.g. Syvitski and Milliman, 2007; Pelletier, 2012) or on smaller catchments in a specific region (e.g. Dunne, 1979; Liénou et al., 2005; Haregeweyn et al., 2008). Very few studies consider a wide range of catchment sizes or regional differences at a continental scale.

Furthermore, tectonic activity is generally not considered as a potential controlling factor of SY (e.g. Milliman and Syvitski, 1992; de Vente and Poesen, 2005; Syvitski and Milliman, 2007; Pelletier, 2012; de Vente et al., 2013) with the exception of some studies in highly tectonically active regions (e.g. Dadson et al., 2003; Hovius et al., 2011). Mostly, it is implicitly assumed that the effects of tectonic activity are either irrelevant or reflected in the catchment topography (e.g. Syvitski and Milliman, 2007). However, recent studies indicate that this is not always the case: spatial variation in soil erosion rates and SY can partly be attributed to spatial differences in seismic activity, even in regions where this activity is relatively limited (e.g. Cox et al., 2010; Portenga and Bierman, 2011; Vanmaercke et al., 2014a,b). Nonetheless, the importance of seismic activity as an explaining factor of SY remains poorly understood. The large variation in land cover and climatic

Table 1
Overview of global sediment yield (SY) inventories, their total number of catchments for which SY was observed, the number of SY observations in Africa, the relative share of SY observations that was measured in Africa and the range of catchment areas (A) for the included African SY observations. 'N.A.' means not available.

Reference	Total # SY-observations	# African SY-observations	% of African observations	A-range Africa (km^2)
Holeman (1968)	110	5	4.5	2.1×10^4–4.0×10^6
Fournier (1969)	139	0	0.0	N.A.
Jansen and Painter (1974)	79	3	3.8	1.1×10^6–4.0×10^6
Walling and Kleo (1979)	1246	13	1.0	N.A.
Dedkov and Mozzherin (1984)	3763	45	1.2	1.9×10^1–3.7×10^6
Jansson (1988)	1358	117	8.6	>300[a]
de Araújo and Knight (2005)	364	23	6.3	2.9×10^{-1}–3.6×10^6
Meybeck and Ragu (1995)	219	24	11.0	9.0×10^3–3.6×10^6
Milliman et al. (1995)	401	43	10.7	3.0×10^2–3.8×10^6
FAO (2008)	869	205	23.6	1.9×10^1–4.0×10^6
Milliman and Farnsworth (2011)	776	66	8.5	1.8×10^1–3.8×10^6

[a] 300 km^2 is the minimum A for the global dataset. The A-range for African catchments could not be retrieved.