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Impact of papyrus wetland encroachment on spatial and temporal variabilities of stream flow and sediment export from wet tropical catchments

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HIGHLIGHTS

- Eight representative catchments were selected in the Lake Victoria basin.
- Runoff discharge and suspended sediment yield (SY) were monitored during one year.
- The presence and status of papyrus wetlands greatly influenced runoff discharge and SY.
- Intact wetlands buffer discharge, trap sediments and decrease connectivity.
- Wetlands can play a crucial role in catchment management strategies.

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ABSTRACT

During the past decades, land use change in the Lake Victoria basin has significantly increased the sediment fluxes to the lake. These sediments as well as their associated nutrients and pollutants affect the food and water security of millions of people in one of Africa's most densely populated regions. Adequate catchment management strategies, based on a thorough understanding of the factors controlling runoff and sediment discharge are therefore crucial. Nonetheless, studies on the magnitude and dynamics of runoff and sediment discharge are very scarce for the Lake Victoria basin and the African Rift region.

We therefore conducted runoff discharge and sediment export measurements in the Upper Rwizi, a catchment in Southwest Uganda, which is representative for the Lake Victoria basin. Land use in this catchment is characterized by grazing area on the high plateaus, banana cropping on the slopes and *Cyperus papyrus* L. wetlands in the valley bottoms. Due to an increasing population pressure, these papyrus wetlands are currently encroached and transformed into pasture and cropland. Seven subcatchments ($358\ km^2$–$2120\ km^2$), with different degrees of wetland encroachment, were monitored during the hydrological year June 2009–May 2010.

Our results indicate that, due to their strong buffering capacity, papyrus wetlands have a first-order control on runoff and sediment discharge. Subcatchments with intact wetlands have a slower rainfall–runoff response, smaller peak runoff discharges, lower rainfall–runoff ratios and significantly smaller suspended sediment concentrations. This is also reflected in the measured annual area-specific suspended sediment yields (SYs): subcatchments with encroached papyrus swamps have SY values that are about three times larger compared to catchments with intact papyrus vegetation (respectively 106–137 ton $km^{-2}\ y^{-1}$ versus 34–37 ton $km^{-2}\ y^{-1}$). We therefore argue that protecting and (where possible) rehabilitating these papyrus wetlands should be a corner stone of catchment management strategies in the Lake Victoria basin.

1. Introduction

The large and rapidly growing population and the high level of poverty in the Lake Victoria basin have led to a high pressure on

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the environment (e.g. Odada et al., 2004; Muyodi et al., 2010), resulting in intense soil erosion and land degradation (e.g. Ntiba et al., 2001; Knapen et al., 2006). Although quantitative data on sediment fluxes are scarce, several studies clearly indicate that deforestation and intensified agriculture in this region have led to a strongly increased sediment input into Lake Victoria over the last decades (e.g. Ntiba et al., 2001; Verschuren et al., 2002; Odada et al., 2004; Swallow et al., 2009).

Various additional challenges are associated with this increased sediment input. For example, sediment-bound nutrients led to important eutrophication problems in Lake Victoria, such as the very extensive bloom of water hyacinths (Witte et al., 1992; Kitaka et al., 2002; Swallow et al., 2003). This, in combination with a decrease in water transparency due the increased turbidity, the onset of deep water anoxia and the introduction of the Nile Perch, caused a collapse of the natural ecosystem of Lake Victoria (e.g. Witte et al., 1992; Hecky, 1993; Lehman, 1996; Ogutu-Ohwayo et al., 1997; Verschuren et al., 2002). Also sediment-fixed pollutants (e.g. mercury) form an important ecological threat to the lake, while the increases in sediment loads have important impacts on water treatment costs (e.g. Mwamburi, 2003; Campbell et al., 2003; Muyodi et al., 2010). Apart from, but closely linked to these sediment-related impacts, the occurrence of floods forms an important problem in the Lake Victoria basin (e.g. Swallow et al., 2009). The frequency, magnitude and impacts of these floods are expected to increase as a result of the predicted climate changes, growing population pressure, the resulting urbanization and other land use changes (e.g. Douglas et al., 2008; Swallow et al., 2009; Lwasa, 2010; Khan et al., 2011). Overall, these problems pose important threats to food and water security, the livelihood of the rapidly increasing population and the socio-economic stability of the region (Ntiba et al., 2001; Verschuren et al., 2002; Odada et al., 2004; Morrison and Harper, 2009; Swallow et al., 2009; Muyodi et al., 2010).

Reliable data on runoff and sediment transport are essential to address these problems of flooding, high sediment concentration and eutrophication in the Lake Victoria basin (e.g. Swallow et al., 2009). However, measured data are very scarce for Eastern and sub-Saharan Africa in general and the Lake Victoria basin in particular (Walling and Webb, 1996; Odada et al., 2004; Verschuren et al., 2002; Vanmaercke et al., 2014a). As an alternative, several studies have attempted to model soil erosion and sediment yield in the region of Lake Victoria (e.g. Lufafa et al., 2003; Cohen et al., 2005; Swallow et al., 2009). However, results obtained from such studies are commonly associated with very large uncertainties, since the applied models were not calibrated for the environmental conditions under consideration (e.g. Maetens et al., 2012; De Vente et al., 2013; Vanmaercke et al., 2014a). For example, Cohen et al. (2005) evaluated the effectiveness of the USLE model in Kenya with field observations and concluded that this model only predicts a small fraction (~30%) of the observed erosion patterns. Field observations therefore remain essential for the calibration and validation of erosion and catchment sediment yield models (e.g. De Vente et al., 2013).

One aspect that remains particularly unclear is the impact of wetlands on runoff and sediment discharge. Wetlands of *Cyperus papyrus* L. are important regulators of nutrient cycles (e.g. Brix, 1994; Kelderman et al., 2007), play a significant role in the conservation of local biodiversity (e.g. Kansiime et al., 2007) and serve as habitat for fish larvae (Mnaya and Wolanski, 2002). Apart from these ecological functions, it has also been argued that these wetlands function as sediment trap and buffer peak discharges (e.g. Cooper et al., 1987; Swallow et al., 2003). Hence, they may be of vital importance in addressing the sediment- and flood-related problems discussed above. Unfortunately, many of the papyrus wetlands in the Lake Victoria basin are under large pressure. At numerous locations, papyrus wetlands are drained, burned and cleared for human settlement and agricultural activities (crop production, cattle grazing), exploited for fuel or building material or as landfill (e.g. Bolwig, 2002; Swallow et al., 2003, 2009; Rwakakamba, 2009; Muyodi et al., 2010; Nakiyemba et al., 2013). Whereas the effects of land use on sediment input in Lake Victoria is recognized (but understudied), the role of the papyrus wetlands and its encroachment is rarely indicated as a potential threat (e.g. Cooper et al., 1987; Boar and Harper, 2002; Mwanuzi et al., 2003; Van Dam, et al., 2007; Kelderman et al., 2007; Morrison and Harper, 2009). This may be partly explained by the fact that no quantitative data exist on the potential runoff buffering or sediment-trapping capacity of these wetlands. As a result, the potential effects that the degradation of these wetlands may have on river flow and sediment discharges are poorly understood.

Hence, there is an urgent need for quantitative runoff and sediment discharge data for catchments in the Lake Victoria basin to allow for the development of effective and feasible catchment management strategies and (in particular) to better understand the possible impact of papyrus wetland encroachment on runoff and sediment discharge. Therefore, the objectives of this study were (i) to obtain runoff and sediment discharge measurements for 8 selected subcatchments in the Lake Victoria basin, having different degrees of wetland encroachment; (ii) to explore the spatial and temporal variabilities in runoff and sediment discharge of these subcatchments; and (iii) to evaluate the potential effect of papyrus wetland encroachment on runoff and sediment discharge.

2. Study area

This study was conducted in the upper Rwizi catchment. This catchment of 2282 km^2 is located in the South-West of Uganda and is part of the Lake Victoria basin (Fig. 1). Seven selected subcatchments, having different degrees of wetland encroachment, of the Upper Rwizi were monitored during one hydrological year (1 June 2009–31 May 2010). Six of these subcatchments are nested (Fig. 1 and Table 1).

The Upper Rwizi catchment is characterized by a rugged topography in the north and the south of the catchment, while the central part consists of a plain. Altitudes in the catchment range between 1248 m and 2159 m a.s.l. (Table 1). The geology of the upper Rwizi catchment is dominated by phyllite rocks. Only in the northern part some granite and sandstone occur (Harrop, 1960). Dominant lithologies per subcatchment are shown in Table 1. The mayor soil types of the upper Rwizi catchment are Ferralsols in the central plain, Regosols in the mountainous northern and southern part of the catchment and Histosols in the papyrus wetlands (Chenery, 1960).

The average annual precipitation in the upper Rwizi is ca. 1150 mm (FAO, 2005). Rainfall is spatially relatively homogenous and ranges from 1216 mm to 1683 mm between the different subcatchments (Table 1), but is characterized by strong seasonal contrasts: average monthly rainfall shows a bimodal distribution with rainfall maxima from March to May and from September to November. Two dry periods separate these rainy seasons. The mean annual air temperature is 20 to 21 °C and varies relatively little throughout the year (FAO, 2005).

Land use in the Upper Rwizi shows a typical topographic sequence, with grazing areas on the high plateaus, banana cropping at the foot slopes and *C. papyrus* L. wetlands in the river valley bottoms (alluvial plains). Many of these papyrus wetlands are currently encroached and transformed into cropland or grazing area (e.g. Bolwig, 2002; Rwakakamba, 2009; Vanonckelen, 2009; Nakiyemba et al., 2013). Table 1 shows the relative area which is occupied by the different land use types for each subcatchment. These numbers are based on an edited and field-verified version of the Africover map (2002), by Vanonckelen (2009). Due to the low resolution of this map and the rapid rate at which wetlands are converted in some regions, exact numbers on the extent of wetland encroachment in each subcatchment were unavailable. Therefore, the state of the wetlands in each catchment was described using three robust classes (Table 1; Fig. 2): severely encroached (less than 20% of the wetlands are remaining), moderately encroached (20–80% of the wetlands are remaining) or minimally