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Determining sources of sediments at Nkula Dam in the Middle Shire River, Malawi, using mineral magnetic approach

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ABSTRACT

Shire River is the largest and longest in Malawi supporting many livelihoods. Degradation in the river's catchment is now a major problem causing excessive siltation in the Nkula Dam which is a terminal sink for sediments eroded and transported by the river and its tributaries. In this study, source of sediments that are deposited into the Nkula Dam were determined by analysing sediment samples from western and eastern tributaries of the Shire River using mineral magnetic approach. Representative samples were collected from tributaries on both sides of the Shire River and Nkula Dam, and subjected to magnetic measurements on bulk samples and sized fractions (<250 μm and >250 μm). Results show significantly higher ferrimagnetic mineral contents and ferrimagnetic to anti-ferromagnetic ratios in the eastern tributaries than the western side of the Shire River. Lithology and weathering conditions are suggested to be the main cause for magnetic contrast between the two sides of the river. It is concluded that most sediments in the Nkula Dam originate from the western side of the Shire River, presumably due to excessive erosion. This study demonstrates that magnetic method is a promising approach in assessing fluvial sediment source.

1. Introduction

Information about sediment source is critical to studies of sediment erosion and deposition in fluvial, coastal and marine systems (Walling, 2005; Zhang et al., 2008; Wang et al., 2010; Yamazaki and Ikehara, 2012; Wilkinson et al., 2013). Methods including geochemistry, mineral analysis and environmental magnetic approach have been used in tracing source of sediment (Walden et al., 1997; Owens et al., 1999; Walling, 2005; Fialová et al., 2006; Zhang et al., 2008; Wilkinson et al., 2013). Most of these studies suggest that particle size is an important factor affecting magnetic properties of sediments, even if they are from the same source (Oldfield et al., 1985; Thompson and Oldfield, 1986; Walden et al., 1997; Wang et al., 2011). This is due to the fact that different particle size fractions contain magnetic minerals of distinct mineralogy, size and amounts (Oldfield et al., 1985; Zhang et al., 2008; Dong et al., 2014; Pulley and Rowntree, 2016). Hydrodynamic variation can result in particle size and density sorting in the process of sediment transport and deposition (Oldfield and Yu, 1994; Venkatachalapathy et al., 2011; Gallaway et al., 2012; Wilkinson et al., 2013). Typically, larger particles and denser components will be transported less downstream compared to smaller and lighter ones. Only a particular fraction of the material eroded on a hill slope therefore, reaches the catchment outlet or downstream due to sediment sorting (Booth et al., 2005; Wang et al., 2010; D'Haen et al., 2013; Skolasińska, 2014; Pulley and Rowntree, 2016). This in turn, will influence magnetic properties of sediments on the pathway from source to sink. Particle-size specific measurement of magnetic properties was therefore introduced to minimize the effect of sorting for sediment source tracing purpose (Oldfield et al., 1985; Hatfield and Maher, 2008; Zhang et al., 2008).

In Malawi, Nkula Dam, which is located in the middle section of the Shire River, is under massive siltation due to unabated anthropogenic activities in the river's catchment, causing reduction

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of the capacity of the Dam reservoir from 14 m to about 1.5 m (Osborne, 2000; Palamuleni, 2010; Birch, 2011; Kaunda and Mtalo, 2013; Mzuza et al., 2015). Although some studies suggest sediments from Lake Malawi might be transported to the Shire River (Owen and Crossley, 1992), it seems that such a contribution is not significant considering the ox-bow lake known as Lake Malombe downstream of Malawi Lake, which may act as a sink of sediments from Lake Malawi. Lake Malombe is an ox-bow lake formed as a result of the meandering and swelling of the Shire River about 19 km away from the mouth of the southeast arm of Lake Malawi. Current studies in the Shire River Basin indicate that tributaries flowing into the Shire River are major sources of sediments downstream (FAO, 1993; Osborne, 2000; Kaunda and Mtalo, 2013). However, there is limited knowledge regarding source of sediment deposited into the Nkula Dam reservoir, particularly considering the contribution of tributaries on both sides of the middle Shire River. This study builds upon magnetic 'fingerprinting' of contemporary river bed sediments in tributaries of the Shire River in Malawi, and attempt particle size-specific magnetic discrimination of sediment source with the aim of contributing to the understanding of the accelerating siltation problem at the Nkula Dam reservoir.

2. Study area and methods

2.1. Study area

Shire River, originating from the south east arm of Lake Malawi (Malawi, southern Africa), is divided into three sections, namely, Upper, Middle and Lower Shire (Fig. 1). The study area (where Nkula Dam is located), lies within the middle part of river, which primarily comprises the Shire Plain - a flat-lying featureless landform on both sides of the Shire River, with elevations ranging from 500 m to 1300 m above sea level (Osborne, 2000). The plain is more extensive to the west of the Shire River consisting of highlands (FAO, 2006). The area experiences a continental tropical climate with two seasons, dry season (May to October) and rainy season (November to April). There are local variations in climate in the Middle Shire area, which are probably due to differences in physiography (Maher, 2007). The eastern part of the Middle Shire receives more rainfall due to its mountainous topography, which is 1150 mm/yr in comparison to 900 mm/yr in the western part year (Kaunda, 2013). Annual temperature ranges from 17 °C to 29 °C, with highlands experiencing lower temperatures than plains. According to data from water gauging stations in the eastern side (Lirangwe River) and western side (Riviridzi River), there is much higher specific flow (two times) in the former particularly in dry season due to a large ground water outflow component (Ministry of Water Development and Irrigation, 2013).

The study area is underlain by Pre-Cambrian Basement Complex gneisses. The dominant rock formations include garnetiferous hypersthene-biotite gneiss, garnetiferous biotite gneiss, and hornblende-biotite gneiss with pyroxene in parts. Quartzo-feldspathic gneisses occurs near Liwonde while perthitic norites and meta-pyroxenites are common south east of the area on the eastern side of the Shire River. Calc-silicate granulites occur as

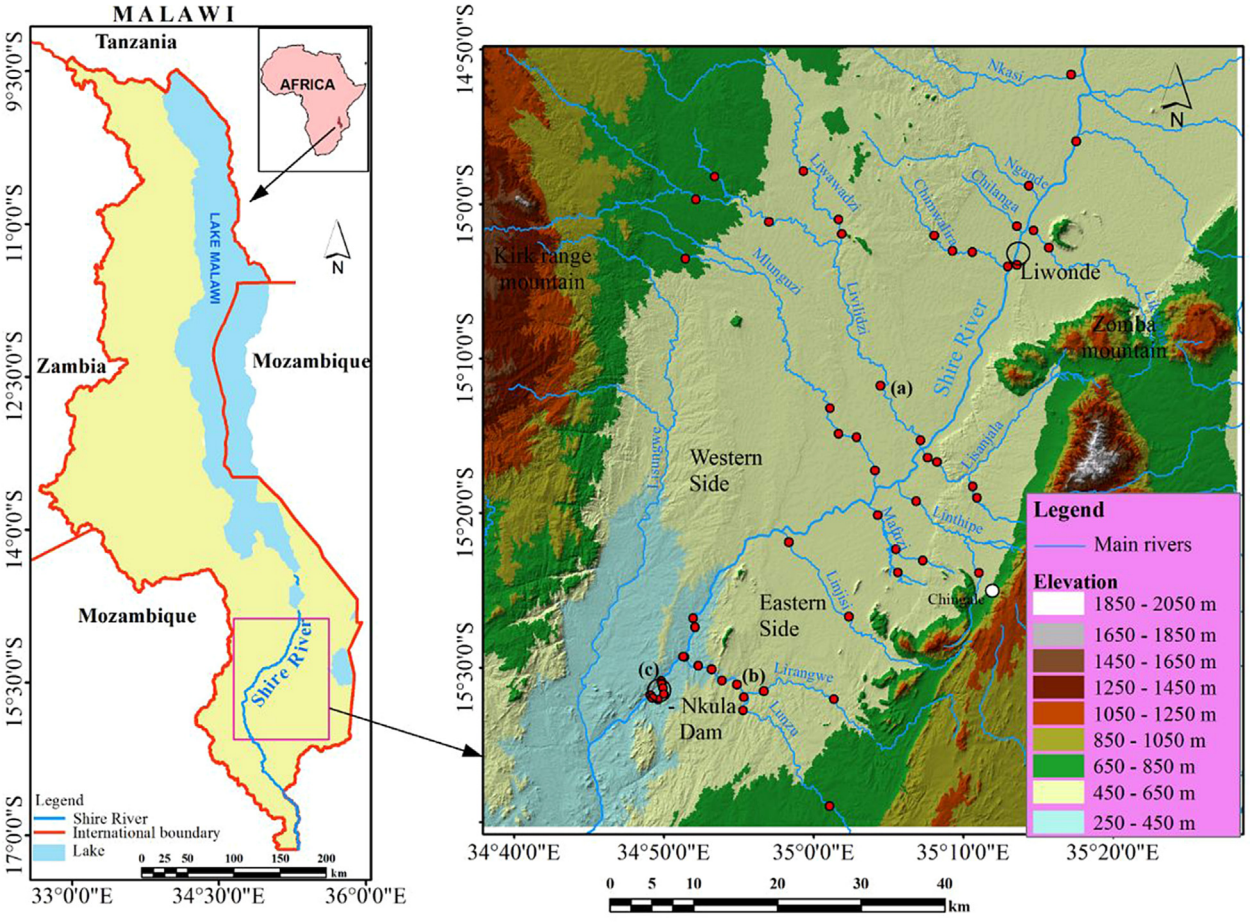

Fig. 1. Map of the middle Shire River, Malawi, showing the sampling sites. The symbols (a), (b) and (c) mark the samples selected for thermomagnetic analysis as shown in Fig. 5.