



## Research article

# Use of sediment source fingerprinting to assess the role of subsurface erosion in the supply of fine sediment in a degraded catchment in the Eastern Cape, South Africa



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## ABSTRACT

Sediment source fingerprinting has been successfully deployed to provide information on the surface and subsurface sources of sediment in many catchments around the world. However, there is still scope to re-examine some of the major assumptions of the technique with reference to the number of fingerprint properties used in the model, the number of model iterations and the potential uncertainties of using more than one sediment core collected from the same floodplain sink. We investigated the role of subsurface erosion in the supply of fine sediment to two sediment cores collected from a floodplain in a small degraded catchment in the Eastern Cape, South Africa. The results showed that increasing the number of individual fingerprint properties in the composite signature did not improve the model goodness-of-fit. This is still a much debated issue in sediment source fingerprinting. To test the goodness-of-fit further, the number of model repeat iterations was increased from 5000 to 30,000. However, this did not reduce uncertainty ranges in modelled source proportions nor improve the model goodness-of-fit. The estimated sediment source contributions were not consistent with the available published data on erosion processes in the study catchment. The temporal pattern of sediment source contributions predicted for the two sediment cores was very different despite the cores being collected in close proximity from the same floodplain. This highlights some of the potential limitations associated with using floodplain cores to reconstruct catchment erosion processes and associated sediment source contributions. For the source tracing approach in general, the findings here suggest the need for further investigations into uncertainties related to the number of fingerprint properties included in un-mixing models. The findings support the current widespread use of  $\leq 5000$  model repeat iterations for estimating the key sources of sediment samples.

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## 1. Introduction

Although some research in a range of environments globally suggests that gully erosion represents an important sediment source (Wallbrink et al., 1996; Wasson et al., 1998; Wilkinson et al.,

2013), it is still a much debated issue (Govers and Poesen, 1988). For example, Wallbrink et al. (1996) found that 90% of the suspended sediment load in the lower Murrumbidgee River, Australia, was derived from subsurface sources and gullies in particular. Wasson et al. (1998) noted that much of the sediment in Australian rivers is derived from gully sources and estimated that the presence of gullies increased sediment emissions by a factor of 10. Poesen et al. (2002) reported that gully erosion represents an important sediment source in dryland environments contributing, on average, 50%–80% of overall sediment production. The effect of gully erosion on sediment generation and catchment scale sediment delivery is,

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however, dependent on the ability of the gullies to route sediment efficiently into fluvial systems (Foster et al., 2012; Fuller and Marden, 2010). This is best described by looking at the degree of coupling (Harvey, 2001) or connectivity (Fryirs et al., 2007), between sediment producing areas and channel systems. Clearly, the role of gully erosion as a catchment sediment source may not be generalized and needs a case by case analysis.

Gully erosion is a major feature of Eastern Cape landscapes in South Africa (Boardman et al., 2015; Kakembo et al., 2009; Keay-Bright and Boardman, 2009; Le Roux and Sumner, 2011). Where the problem is most serious, large expanses of land are heavily dissected forming extensive so-called 'badlands'. Most of these are deeply incised into colluvial hill slopes and weathered shale bedrock (Boardman and Foster, 2008; Boardman et al., 2015; Kakembo et al., 2009). Studies have found that gullies differ in size in response to different factors. For example, Dollar and Rowntree (1995) measured gullies up to 22 m wide and 13 m deep in cultivated fields in the Bell River catchment. Hanvey et al. (1991) described gullies 20 m wide and 16 m deep on a fossil dune complex in the east coast of South Africa. Gullies eroding on bedrock in the arid landscapes of the Karoo region of the Eastern Cape in South Africa, have been known to reach depths of 5 m and widths of over 20 m and even deeper in valley bottoms (Boardman and Foster, 2008). Both short and medium term rates of gully erosion have been estimated in the Eastern Cape province. For example, Boardman et al. (2010; 2015) reported gully erosion rates of between  $32.3 \text{ t ha}^{-1} \text{ y}^{-1}$  and  $136 \text{ t ha}^{-1} \text{ y}^{-1}$  in the Karoo. Other studies have estimated gully erosion rates in terms of changes in spatial extent on the basis of aerial photographs. Dollar and Rowntree (1995) noted an increase in the total gully length of 69% between 1952 and 1975 in the Bell River catchment, Eastern Cape and by a further 169% up to 1991. Vetter (2007) noted a substantial increase in erosion from 1950 to 1995 in the Sterkspruit District with more than 50% of the surface area affected by sheet, rill or gully erosion by 1995.

Investigations have reached varied conclusions in relation to the linkages between gully erosion and high sediment yields in catchments of the Eastern Cape province. Foster et al. (2007, 2012) reported that rather than being a major source of contemporary sediment, gullies only provide connectivity between the eroding upper section and the river systems in some of the catchments in the Karoo region. This was consistent with Keay-Bright and Boardman (2006) who reported that gully and badland expansion in the same region has slowed down, stabilized and even decreased. However, Rowntree and Foster (2012) reported that regardless of the above observation, some gullies continue to erode at high rates and continue acting as 'partial areas' for sediment contribution to river systems even when the badland area is relatively reduced in size.

It is known that sheet and rill (i.e. top soil source) and gully and bank erosion (i.e. subsoil sources) are the major sources of the fine-grained bed and suspended load in many river systems (Wethered et al., 2015). However, the contributions of topsoil and subsoil vary from catchment to catchment undermining generalisations. Knowledge of the relative importance of surface and subsurface sources of sediment helps identify the main erosion process mobilizing sediment and thus provides assistance in the design and targeting of rehabilitation measures to reduce downstream sediment loads and associated off-site impacts. This information may also be important to understand catchment sediment delivery processes and the degree of lateral and longitudinal (dis)connectivity of the catchment sediment cascade (Fryirs et al., 2007; Koiter et al., 2013a,b; Wethered et al., 2015). Given the uncertainty surrounding the role of gullies as a sediment source in South African catchments, this study explores the issue further by focussing on a

catchment located in the Ngqushwa Local Municipality, Eastern Cape, South Africa, where severe soil erosion resulting from land use change has led to landscape dysfunction (Kakembo et al., 2009) and excessive sedimentation in the local stream channels (Kakembo and Rowntree, 2003).

Quantitative sediment source fingerprinting has demonstrated potential to help reconstruct historical sediment source dynamics in terms of surface and subsurface contributions on the basis of the sediment signatures preserved in floodplain sediment cores (Collins et al., 1997b, 2010a; Owens et al., 1999). Different types of mixing models or algorithms have been used to estimate the relative contributions of potential sediment sources (see Collins et al., 1997b; Fox and Papanicolaou, 2008; Nosrati et al., 2014). The type and structure of statistical mixing models can significantly affect the estimates of source contributions (Haddadchi et al., 2014; Smith et al., 2015; Cooper et al., 2014), hence they constitute a significant research issue for sediment fingerprinting studies. Besides the type of models, recent research has shown that there are many other factors that may influence the consistency or accuracy of the estimates of source contributions obtained from sediment source fingerprinting models and thus needing further research. These include the use of correction factors and weightings (Smith and Blake, 2014; Laceby and Olley, 2015; Laceby et al., 2015; Collins et al., 2010b), the issue of conservativeness of the fingerprints used (Laceby and Olley, 2015; Pulley et al., 2015), source group classification (Pulley et al., 2017), the number and type of tracers included in the mixing model (Martinez-Carreras et al., 2008; Koiter et al., 2013a,b; Sherrieff et al., 2015; Smith and Blake, 2014; Pulley et al., 2015) and the use of either local and global optimization methods (Haddadchi et al., 2013; Collins et al., 2010c; Collins et al., 2012). However other issues that have the potential to influence the outputs from mixing models require examination, including the number of repeat iterations and the use of different sectioned sediment cores in the case of floodplains.

In the context of the above background, this paper specifically aimed to: 1) examine the potential impact of numbers of properties in optimised signatures, number of model iterations and the use of replicate depositional sink sampling on the modelled sediment source estimates generated, and; 2) use sediment source fingerprinting to assess the extent to which the supply of fine-grained sediment in the study catchment is dominated by gully and stream bank erosion.

## 2. The study area

The study catchment (90 km<sup>2</sup>) is located south of the town of Peddie, Eastern Cape province, South Africa (Fig. 1). Topography is generally undulating, rising from sea level on the coast to about 365 m above sea level in the north. Slopes rise steeply (>10°) alongside major stream channels. The catchment is dominated by shale and arenite of the Ecca Group and Karoo Supergroup (Permian-Triassic). The Ecca Group shale weathers to form highly erodible soils (Mills and Cowling, 2006). Greyish brown shallow litholic soils of the Mispah and Glenrosa Form (Entisols and Inceptisols in Soil Taxonomy) which are dominant in the catchment, are typically low in organic matter content and sometimes with high sodium content (Kakembo and Rowntree, 2003). Severe soil erosion which ranges from sheet and inter-rill erosion in grazing lands to gully erosion in abandoned cultivated lands has been well documented in the study catchment (see Kakembo, 2009; Kakembo and Rowntree, 2003; Kakembo et al., 2009; Manjoro et al., 2012a). Gully erosion is mostly predominant in lower slope positions.

The average annual rainfall is 491 mm and is bi-modally distributed, with peaks in October or November and March or

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