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Alluvial aquifer characterisation and resource assessment of the Molototsi sand river, Limpopo, South Africa

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ABSTRACT

Study region: Molototsi sand river, Limpopo, South Africa.
Study focus: Ephemeral sand rivers are common throughout the world's dryland regions, often providing a water source where more conventional sources are unavailable. However, these alluvial aquifers are poorly represented in the literature. Extensive field investigations allowed estimation of stored water volume and characterisation of an alluvial aquifer.
New hydrological insights for the region: Computed alluvial aquifer properties included hydraulic conductivity of 20–300 m/d, porosity of 38–40%, and aquifer thickness of 0–6 m. Dykes and other subcrops commonly compartmentalise the aquifer though do not form barriers to flow. A hydraulic disconnect between deep groundwater (occurring in fractured metamorphic rocks) and the alluvial aquifer was revealed by groundwater levels and contrasting hydrochemistry and stable isotope signatures. The dominant recharge process of the alluvial aquifer is surface runoff occurring from torrential tributaries in the catchment's upper reaches. A fraction of available storage is currently abstracted and there exists potential for greater exploitation for smallholder irrigation and other uses.

1. Introduction

Ephemeral sand choked rivers commonly occur in the world's dryland regions. Such systems experience surface flows only following infrequent torrential rainfall (Tooth, 2000). Where the underlying geology is of low permeability, e.g. African crystalline basement, infrequent torrential flows fully recharge the alluvial aquifer creating an accessible water resource where unfavourable climate and geology create few alternatives. Drylands occupy 41.3% of the world's surface and are home to 2.1 billion people (UN, 2017), many of whom obtain their water supplies from resources contained within "sand rivers" (Seely et al., 2003; Love et al., 2011). Smallholder irrigation often obtains water from sand rivers where minimal head difference and proximity of river channel to riparian fields minimises equipment and energy costs. The relatively low stored water volumes can be sufficient for small-scale farming activities (Hussey, 2007; Love et al., 2007).

South African agricultural policy makers and farmers recognise that subsistence/smallholder agriculture can reduce the

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vulnerability of food-insecure households, improving livelihoods, boosting nutritional intake, and help mitigate food price inflation (Wenhold et al., 2007; Baiphethi and Jacobs, 2009). Most poor and food-insecure households in South Africa are concentrated in former rural homeland areas. Increased food productivity by subsistence and smallholder farmers in these areas would enhance long-term food security reversing the decline of smallholder agriculture (Baiphethi and Jacobs, 2009; Pereira and Drimie, 2016). The decline in smallholder farming is in part due to increased failure of borehole and surface water sources, especially poorly maintained systems installed before 1994 (personal communication, local farmers, October 2016 and May 2017). Identification of alternative cheap water sources to enhance smallholder agriculture should be prioritised. Sand rivers are potentially such alternative water sources.

Sand rivers are defined as shallow unconsolidated alluvial deposits presently accumulating along active stream courses within which thin saturated basal sands form limited aquifers. The depth to water table is less than a two metres, within unconsolidated sands that are regularly recharged. Sand rivers can be considered a renewable resource where long-term groundwater depletion is not expected if used sustainably (Owen, 1989). Moderate yields are possible from permeable alluvial deposits with high initial specific yield. However, the stored volume is often a limiting factor as sand rivers range in width from 10 to 100s m and in thickness from 1 to 30 m. Water qualities are generally good due to frequent recharge and the filtering effect of the sand (Nord, 1985; Owen and Dahlin, 2005; Cobbing et al., 2008). Sand river aquifer recharge is almost entirely from surface water flow during occasional floods generated by torrential rainfall events; little recharge results from normal annual precipitation (Owen and Dahlin, 2005).

Similar landforms elsewhere in the world, such as wadis in the Middle East (e.g. Meirovich et al., 1998; Gheith and Sultan, 2002) and arroyos in southwestern USA (e.g. Reid and Frostick, 1997; Graf, 1988), are fairly well-researched, due to local recognition of their value, local research capacity, and data availability (Tooth, 2000). In contrast, sand rivers in Africa have received little attention in peer-reviewed literature. Much of the research is available only in grey literature. Handbooks by Nissen-Petersen (2006) and Hussey (2007) provide guidance for the exploitation of sand river water resources. Reports describing the exploitation of sand rivers in Botswana are presented by Davies et al. (1998) and Herbert et al. (1997), in Zimbabwe by Owen (1989), and in Southern Africa by Clanahan and Jonck (2004). Regarding aquifer characterisation studies, geophysics was used to assess aquifer geometry by Owen and Dahlin (2005) in Zimbabwe and Arvidsson et al. (2011) in Mozambique. Field tests for aquifer parameters in Botswana are described by Davies et al. (1998), in Zimbabwe by Mansell and Hussey (2005) and Love et al. (2007), and sand river resource assessments in Zimbabwe using modelling are presented by de Hamer et al. (2008) and Love et al. (2011). Moyce et al. (2006) and Mpala et al. (2016) conducted water resource assessments using remote sensing techniques. Investigations on the Kuiseb sand river in Namibia are reported by Dahan et al. (2008); Morin et al. (2009) and Benito et al. (2010). Outside of these areas, there are few published aquifer characteristic data for assessment of the sustainability of sand river exploitation (Mansell and Hussey, 2005). This study contributes data from field investigations and observations of a sand river currently utilised for small-scale irrigation. The objectives include characterisation of aquifer properties, geometry and relationship between surface water, and shallow and deep groundwaters. The study aims to estimate the stored water volume to determine if the resource is being used sustainably and potential for further exploitation. The Molototsi study site is typical of sand rivers found in the wider region, overlying crystalline basement rocks and receiving infrequent surface flows. Increased exploitation of sand rivers in the region could mitigate the impact of borehole and surface water infrastructure deterioration by increasing food security, alleviating poverty and boosting nutritional intake.

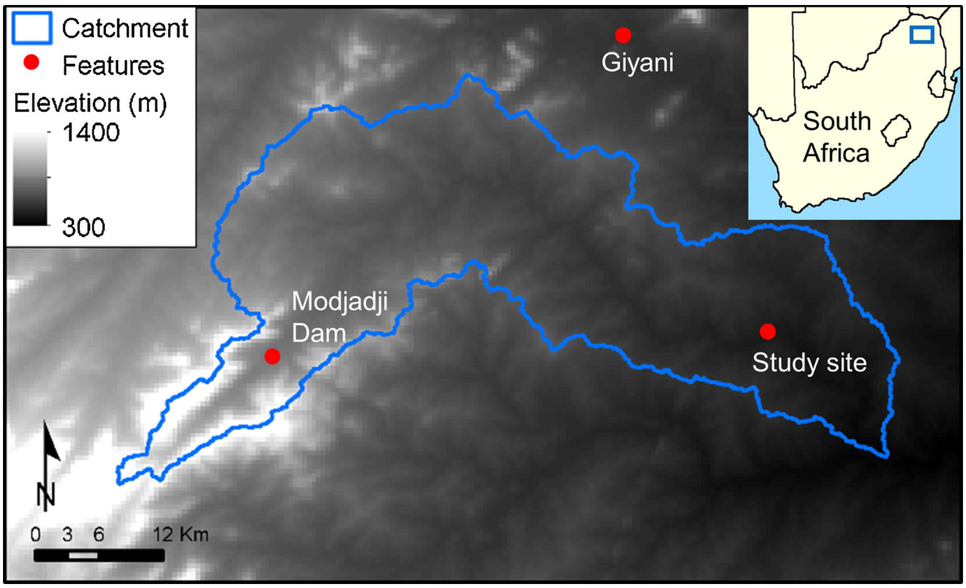

Fig. 1. Study site location.