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The hydrology of sand rivers in Zimbabwe and the use of remote sensing to assess their level of saturation

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ABSTRACT

Sand rivers are ephemeral watercourses containing sand that are occasionally flooded with rainwater runoff during the rainy season. Although the riverbed appears dry for most of the year, there is perennial groundwater flow within the sand. This water flowing beneath the surface is a valuable resource for local communities; nonetheless our understanding of such river systems is limited. Hence, this paper aims to improve our understanding of the hydrology of sand rivers and to examine the potential use of remote sensing to detect the presence of water in the sand. The relationship between rainfall events and changes in the water level of two sand rivers in the Matabeleland South Province of Zimbabwe was investigated. A lagged relationship was observed for the Manzamnyama River but for the Shashani River the relationship was seen only when considering cumulative rainfall events. The comparison of the modelled flow as simulated by a water balance model with observations revealed the important influence of the effective sediment depth on the recharge and recession of the alluvial channels in addition to the length of the channel. The possibility of detecting water in the alluvial sands was investigated using remote sensing. During the wet season, optical images showed that the presence of water on the riverbed was associated with a smooth signal, as it tends to reflect the incident radiation. A chronological analysis of radar images for different months of the year demonstrates that it is possible to detect the presence of water in the sand rivers. These results are a first step towards the development of a methodology that would aim to use remote sensing to help reducing survey costs by guiding exploratory activities to areas showing signs of water abstraction potential.

1. Introduction

Sand rivers, also called *luggas* in East Africa and *wadis* in North Africa and the Middle East, are ephemeral watercourses containing sand, which are flooded with rainwater runoff once or a few times in a year (Herbert, 1998; Hussey, 1997; Nissen-petersen, 1998). These rivers are the prevailing river type in the arid and semi-arid regions of southern Africa (Davies et al., 1994). Even though no water flows in the river bed for most of the year, there is perennial flow within the sand (Herbert, 1998). Fig. 1 shows a typical sand river during the wet and dry season.

In southern Africa, particularly in Botswana and Zimbabwe, sand rivers are acknowledged as a potential source of drinking water, although their use is limited to a few small-scale water abstraction systems in remote rural communities. These sand water abstraction systems have the potential to augment supplies from established water supply systems, but have not been developed nor adopted by national water supply authorities (Hussey, 2007). Hence, water from sand rivers is not fully exploited in many areas where it could provide an essential source of water supply. For example, in 1998 it was estimated that there were approximately 900 km of sand rivers in Botswana with the potential to supply water to approximately a third of the country population at the time (Herbert, 1998). However, it is not clear what the size of the resource is in comparison with traditional surface and groundwater resources.

Shortly after a rainfall event, the water in a sand river recedes below the surface; nonetheless, it remains accessible by digging up to a certain depth (see Fig. 1(c)), which depends on the time that

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Fig. 1. The Shashani River during the wet (left) and dry season (centre), and illustration of the depth of the water level during the dry season (right).

elapsed since the end of the rainy season. Limited research has been conducted to date on the factors controlling the flow within the alluvium of ephemeral rivers. Love (2013) studied the influence of rainfall on the discharge of sand rivers in the Zhulube catchment of the northern Limpopo Basin of Zimbabwe. He observed that the recession after a rainfall event is typically short, in the order of a few days, and is caused by the rapid drying out of the shallow soils. The recession time was found to be longer, however, subsequent to larger floods caused by intense precipitation. For these reasons, he identified soil types and rainfall intensity as the two main factors influencing the recession time of a sand river. Mansell and Hussey (2005) also noted the influence of rainfall intensity on the recession time of a sand river but found that the flow velocity within the alluvium and the plan area of the channel were also important factors.

In Zimbabwe, sand rivers are increasingly used by non-governmental organisations (NGOs) to provide water in water stressed communities. The suitability of a sand river for effective and reliable abstraction of water depends on its gradient, width of the channel, the depth and grading of sediment, as well as the permeability and porosity of the soil. Hence, before a sand river is selected for water abstraction extensive appraisals, incorporating topographical surveys and GPS mapping, and probing and analysis of sediments have to be carried out. Such surveys can be costly and out of reach to many NGOs. The use of remote sensing to identify sand rivers showing signs of water abstraction potential could potentially reduce survey costs by guiding ground surveys to areas having shown signs of potential.

This paper comprises two objectives. The first objective aims to improve our understanding of the hydrology of sand rivers by presenting water level measurements taken on two rivers situated in the semi-arid region of south-western Zimbabwe, and to demonstrate how the water level in the sand rivers is related to rainfall and the characteristics of the river channel and catchment.

Continuous daily monitoring of the water level in a sand river using remote logging devices has not been previously done at the scale presented here. Research has to date been limited to direct measurements taken by research assistants, hence bringing in human error and inconsistencies, but which are eliminated by the accuracy and precision of a well calibrated water-level logger. The second objective is to examine the potential use of remote sensing to identify river channels with significant sediment deposits and to detect the presence of water within the alluvium. Previous research has shown the potential for using optical and radar images in feature identification and moisture detection, respectively, in different land cover types, but the usefulness of remote sensing to detect water in sand rivers has yet to be determined.

In the early 1980s detection of underground water was shown to be possible through long wave radar such as carried by the Shuttle Imaging Radar (SIR) systems, although the detection was only up to a few metres. Penetrations up to 6 m were documented at a 23.5 cm wavelength under ideal conditions (Elachi et al., 1984). In general, for penetration to occur the overlying material must be less than 2 m thick, the moisture content must be very low, and the surface must be rough to generate enough backscatter of the radar signal (Ford et al., 1989). Very few areas in the world are able to meet these conditions and this method is limited to buried river channels in the deserts of North Africa and the Middle East (Abdelsalam et al., 2000).

Another possibility to detect underground water remotely is through heat detection, as saturated soils have a greater heat capacity than dry soils (Becker, 2006). Thus, groundwater can be detected by large-scale thermal infrared (TIR) imagery because the relatively warm groundwater, especially at night, provides a contrast with the cool soil temperatures (Heilman and Moore, 1982).

2. Study area

The ephemeral river systems presented in this study, i.e., the Manzamnyama and Shashani rivers, are both located in the Matabeleland South Province of southwestern Zimbabwe (Fig. 2). The two rivers were chosen as they are currently sustaining small-scale sand water abstraction systems installed by the Dabane Trust. The Manzamnyama (or Nata) River flows in both Zimbabwe and Botswana; it is 330 km long from its source to mouth, 210 km of which are in Zimbabwe and 120 km in Botswana, and its total catchment area is 24,585 km^2. The river originates in a small farming town named Sandown located on the Zimbabwean central watershed 50 km south west of Bulawayo and ends in the Makgadikgadi saltpans of Botswana.

Field visits together with analyses of high-resolution satellite images show that the upper reaches of the Manzamnyama River are located in a commercial farming area where the Mananda Dam, a major dam on the Manzamnyama River, is located. Measurements of geo-referenced and ortho-rectified satellite images in a geographical information system (GIS) have shown that significant sedimentation begins to occur about 65 km along the river course marking the beginning of a 90 km stretch where the river passes through communal farming areas. It is on this stretch where the water abstraction potential of the ephemeral river is realised with communities relying on this water resource for domestic usage as well as for small-scale gardening and livestock farming. Hence, the current research focuses on this 90 km long section of the Manzamnyama River.

The Shashani River is a major tributary of the Shashe River. Like the Manzamnyama River, the Shashani River originates in the town of Sandown, but flows south (Fig. 2). The Shashani River is 206 km long; it also a multi-faceted river, being used for commercial water supply for the upper half of its length and for communal water supply through sand water abstraction for the remainder of its course. In the commercial areas the Shashani River is dammed at