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Baseflow prediction in a data-scarce catchment with Inselberg topography, Central Mozambique

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ABSTRACT

This study aimed to improve the understanding of hydrological processes in a humid (sub)tropical area in Africa with Inselberg topography. Additionally, the study intended to develop an approach for selective discharge data acquisition to determine water availability for smallholder irrigation in similar data-scarce catchments. During the December 2012–August 2013 field campaign meteorological and river stage data were collected at the Messica catchment in Central Mozambique. The 220 km^2 catchment has an estimated 1000 ha of irrigated land, developed by smallholder farmers. Baseflow in the perennial tributary streams on the slopes of a meta-sedimentary Inselberg is the source of irrigation water. The baseflow recession curve of one of these tributaries is analysed and the water balance of an average year was determined. Precipitation, potential evapotranspiration, actual evapotranspiration and discharge were estimated to be 1224, 1462, 949 and 266 mm/year respectively. Differential gauging showed that the perennial tributaries gain water; the groundwater contribution increased with approximately 50% over two and a half month relative to the downstream discharge from March to May. In the downstream parts the groundwater contribution per metre stream length is between 30% and 100% higher compared to the upstream parts for two of the tributaries. Nevertheless, due to natural streambed infiltration and irrigation canals, discharge varies over the length of these tributaries. A rainfall–runoff model (HBV) was calibrated using the field data to examine the relation between precipitation characteristics and discharge at the start of the dry season. For precipitation scenarios with low and high intensity precipitation, discharges from June onwards were approximately similar in size according to the calibrated model. This suggest that discharge at the start of the dry season is mainly determined by total precipitation and the timing of precipitation (i.e. early or late in the wet season), not by individual rainfall events or rainfall intensity. It is concluded that the use of selective discharge measurements and low frequency precipitation measurements can effectively be used for water availability assessments in Inselberg catchments. Further research should be conducted to verify the validity of the used techniques in other humid sub-tropical Inselberg areas.

1. Introduction

This study aimed to improve the understanding of hydrological processes in a humid (sub)tropical area in Africa with Inselberg topography and to test the use of limited discharge data to determine water availability for smallholder irrigation. Irrigated production is known to expand in Africa mainly through an increase in irrigated area developed by smallholder farmers, with annual growth rates as high as 3.8% in some parts of Tanzania. The Messica catchment in Central-Mozambique hosts a large community of smallholder farmers. The tributaries of the Messica river form the main water supply for smallholder irrigation developed by them (Lankford, 2005). Detailed research in Messica (Beekman, forthcoming) identified approximately 1000 ha of smallholder irrigation command area, compared to an estimated 340 ha in 2010 and none in 2003. Assuming similar agro-ecological zones within the province of Manica (with irrigation densities as found in Messica), the extent of smallholder irrigated areas could be between 100 000 ha and up to 300 000 ha. FAO Aquastat (2011) reported

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a total of 118 000 ha of irrigation infrastructure in Mozambique, including large scale systems (based on data from 2003), of which only 40 000 ha are currently in use. This comparison clearly demonstrates the importance of smallholder irrigation.

These smallholder irrigation systems use water resources that remain unmapped. Because of the increase in rural population and irrigated agriculture, these natural resources become increasingly strained. With the expected increase in irrigated agriculture, sustainable water resource management is pivotal. The Messica catchment has geological and hydrological characteristic similar to many headwater areas in southern and eastern Africa. These river systems are an important source of water for smallholder production. Insight in the hydrology of these characteristic headwater catchments is paramount for the successful implementation of sustainable and cost-effective pro-poor smallholder irrigation development.

The characteristics of the Messica catchment are typical for headwater areas with comparable geology and climate, such as frequently found in southern and eastern Africa. Insights gained in this hydrological study could therefore be scaled up and extrapolated to other regions. The Messica catchment is chosen as a pilot study area to coincide with an irrigation development study (the Messica Irrigation Pilot Project or MIPP). That study aims to demonstrate demand-led, flexible outcome approach to irrigation development by means of an innovative institutional model. The study focuses on an approximated 1000 ha smallholder irrigation area in the eastern Messica catchment. The successful implementation of the MIPP project will show that sustainable and pro-poor smallholder irrigation can be developed cost-effectively at a large scale. Additionally it aims to provide an answer to the challenges faced by large-scale investment programmes and prove the institutional model as an essential part in the successful implementation of these programs. A standardised cost-effective approach for hydrological surveys as an integral part of all irrigation development in comparable regions would further enhance the chances of successful development of irrigation. Combining the insights gained in the MIPP project with the outcome of this hydrological study, could therefore lead to an integral, standardised and cost-effective approach for sustainable irrigation development.

With this background four different techniques were applied in the Messica catchment: a water balance, dry season baseflow recession, differential gauging and a rainfall–runoff model (HBV). In this section those techniques will be discussed briefly. A water balance was obtained for the complete study area (Messica catchment; 220 km^2) and a tributary stream catchment (Godi catchment; 10 km^2). This was done in order to get a better understanding of the hydrological system. The dry season baseflow recession of the Godi stream was studied to test if baseflow recession during the dry season can be described by a single exponential function based on a limited number of discharge measurements at the start of the dry season. This technique can be used for forecasting baseflow of Godi stream and if verified in other Inselberg catchments, as well in other regions. Differential gauging was applied to get a better understanding of the hydrological processes of this particular Inselberg. A rainfall–runoff model was calibrated to see to what extend predictions can be made based on limited time series of discharge and to test what rainfall characteristics are required to predict baseflow at the start of the dry season.

The first hypothesis of this study is that baseflow recession during the dry season can be described by a single exponential function based on a limited number of discharge measurements at the start of the dry season. The second hypothesis is that baseflow at the start of the dry season is not only determined by monthly or seasonal precipitation totals but also by the duration and intensity of precipitation in the wet season and that by establishing a relation between discharge and rainfall characteristics during the wet season, baseflow at the start of the dry season can be predicated.

2. Study site

The Messica river catchment is located in the Manica Province, Central Mozambique and is approximately 220 km^2 in size (Fig. 1). The Manica province is mainly agriculturally based, and is an important producer of a wide range of fruits and vegetables. The Messica River flows into an artificial dam, located south of the Manica – Chimoio Road (EN6). The river catchment is mostly characterised by gentle sloping agricultural land (smallholder farms) and is located in wide flat valley. This study will focus on the agricultural fields in the easternmost part of the Messica catchment, which is characterised by an elongated ridge (Inselberg) with a maximum height of approximately 1450 m above sea level. The ridge lies approximately 800 m higher than the Messica River and is covered by a deciduous forest.

2.1. Geology

Fig. 2 presents an excerpt of the geological map of Mozambique (Instituto Nacional De Geologia, 1987). According to Koistinen et al. (2008) the geology of the study area is formed by an extension of the Zimbabwean Craton and consists of Archaean and Paleoproterozoic rocks. West of Manica lies the Irumide Belt, which is an extension of the Zimbabwean greenstone belt. The geology of the lower parts of the Messica catchment is made up of granitoids and gneisses, the higher situated Inselbergs consist of rocks from the Gairezi Group. In the east the Craton terminates against the younger Mozambique belt. The oldest cover rocks on the basement belong to the metasedimentary Gairezi Group. The Gairezi Group is composed of quartzite and mica schists. Occurrences of conglomerate are found below the quartzite southeast of Manica. The quartzites are composed of very coarse sugary quartz. The attitude of the cover rocks is flat or gently east-dipping. The Gairezi quartzite and Micaschists outliers in the area form highly compressed, upright, narrow subcontinuous and interlocking synclines, with horizontal north–south axes, which form the prominent Inselbergs in the study area. Inselbergs are steep-sided mountains, ridges, or isolated hills that rise abruptly from adjoining plains or gently sloping areas. Inselbergs are a common feature in settings with a tectonically stable crystalline basement geology, which is widely found in southern and eastern Africa (Koistinen et al., 2008).

2.2. Hydrology and meteorology

The Messica River is north–south oriented and flows into an artificial lake to the south (the Chicamba Lake). Typical to many headwater areas in this region, land use is a mixture of rainfed farming and woodland. On the slopes of the Messica catchment, smallholder farmers use the river water for irrigation of small plots (from 0.5 up to 5 ha), for commercial crops such as tomatoes and other vegetables and fruits. In the south eastern corner of the catchment detailed research identified that a total area of approximately 1000 ha is currently under command area of which 400–600 ha is irrigated (Beekman, forthcoming).

The catchment is characterised by gentle slopes along the valley floor, drained by the perennial Messica River. On the eastern side, the catchment is flanked by a steep rocky ridge (Inselberg), drained by streams in which baseflow is maintained during the dry season. This study was done in two of these tributaries streams, the Chirodzo (9 km^2) and the Godi (10 km^2). The latter is selected as a case-study, since this stream was assumed to be the best representative for the tributary streams.