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Hydrograph separation using hydrochemical tracers in the Makanya catchment, Tanzania

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Abstract

Hydrochemical tracers were used to separate and quantify different runoff components in the semi-arid Makanya catchment in the South Pare Mountains of Tanzania. One flood event was investigated during the rainy season of October–December 2005 and analysed for electrical conductivity, dissolved silica and major anions and cations. The event on 9 November 2005 showed two peaks, each originating from one of two sub-catchments, upper-Vudee and Ndolwa, each with a distinct water quality signature. Hydrograph separation indicated that the two peaks in the hydrograph originated from a delay in response between the two catchments. The hydrograph separation indicated that, for this event, over 95% of the discharge could be attributed to sub-surface runoff, while the remainder was due to faster surface runoff processes. The dominance of sub-surface processes was also indicated by the lack of suspended sediments in the samples, which is a clear indication that no surface runoff took place.

Keywords: Hydrological processes; Pangani basin; Runoff generation

1. Introduction

In many parts of the world catchments are not or poorly gauged. In particular in developing countries, catchments are predominantly ungauged, as a result of lack of adequate resources (Mazvimavi, 2003). There are two main factors in sub-Saharan Africa that affect the predictability of hydrological responses. First, the climatic variability is both spatially and temporally very high. Additionally, increasing population densities and the resulting dynamic land use changes affect hydrological responses.

Chemical hydrograph separation is a method to define the origin and composition of the runoff during floods (Uhlenbrook et al., 2002). This method is based on the mixing of two or more water types with known and distinct hydrochemical characteristics, where the ratio of mixing determines the concentrations in the stream. Chemical hydrograph separation is predominantly done to separate subsurface and surface runoff. Pre-event ("old") and event ("new") water can be separated using environmental isotopes (Hooper and Shoemaker, 1986). Uhlenbrook et al. (2002) also used a chemical method for a separation between event water, shallow groundwater, and deep groundwater, using isotopes and dissolved silica (3-component separation). Hydrochemical tracers, such as Ca^{+}, Mg^{2+}, SO_4^{2-} and Cl^{-} are relatively inexpensive to analyse and easy to use for hydrograph separation (Ribolzi et al., 2000; Soulsby et al., 2004; Tardy et al., 2004; Wels et al., 1991). The main challenge with using these tracers is that the original concentrations can change along the specific flow path (non-conservative behaviour). With a limited amount of time between rainfall and runoff, this can be

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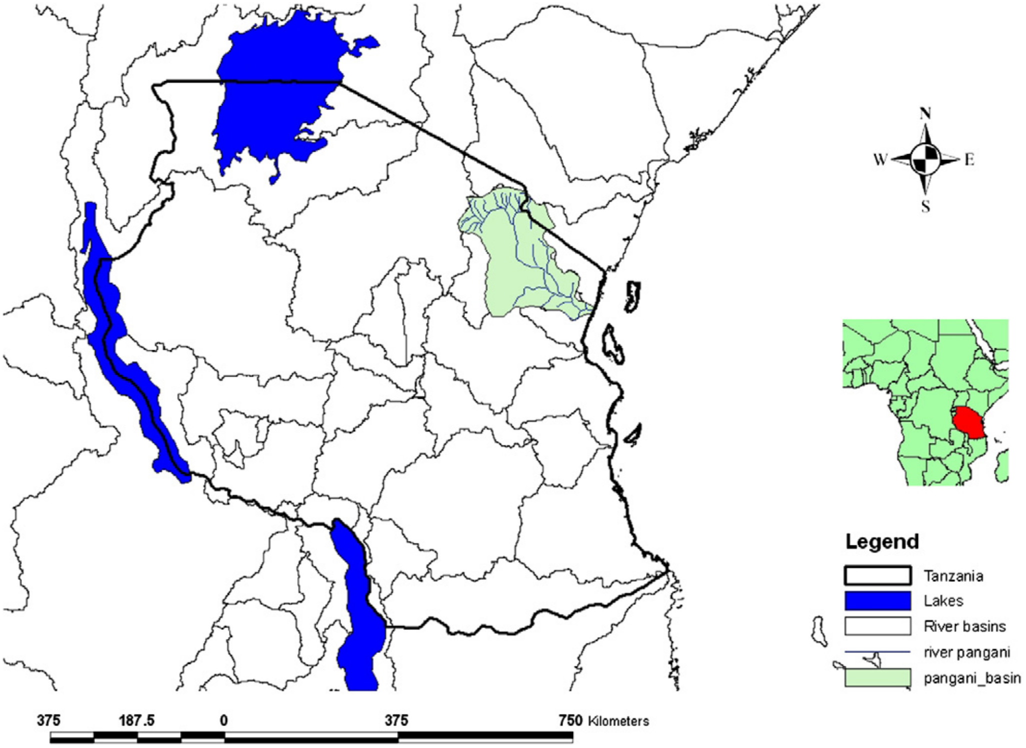

Fig. 1. Location of Pangani River Basin in Tanzania.

neglected. Although more expensive, hydrograph separation can also be done using isotopes, or a combination of isotope and chemical tracers (Sklash and Farvolden, 1979; Buttle, 1994; Ladouche et al., 2001 and Marc et al., 2001).

Chemical hydrograph separation has been mostly applied in humid temperate climates. This paper describes the application of this method using hydrochemical tracers in a semi-arid meso-scale catchment. The Makanya catchment is located in the South Pare Mountains, northern Tanzania. It is part of the Pangani river basin, one of the nine river basins in Tanzania (Figs. 1 and 2). It is a poorly gauged catchment with two rainfall stations with a record of more than 10 years, and without any long records of discharge measurements. Rainfall in the catchment ranges from 550 mm yr^{-1} in the lowlands ($\sim$700 m) to 800 mm yr^{-1} in the highlands (up to 2000 m) and is distributed over two rainy seasons. The short rainy season, locally known as "Vuli" runs from October to December, whereas the long rainy season, locally known as "Masika" runs from March to May. In 2004, the SSI Programme (Rockström et al., 2004) installed a hydrological monitoring network in the catchment, and has since been researching the hydrological implications of changing farmer management practices. The objectives of this study are to investigate the applicability of using hydrochemical tracers for hydrograph separation in a meso-scale semi-arid catchment in Tanzania.

2. Methodology

In this paper, chemical hydrograph separation for one relatively small flood event is described, using hydrochemical tracers including electrical conductivity (EC), dissolved silica (SiO_2), and major anions and cations. The flood event occurred on 9 November 2005, during the short rainy season in a sub-catchment of the Makanya catchment. The Vudee sub-catchment is monitored after the confluence of two rivers, upper-Vudee and Ndolwa (Fig. 2). At this location, discharge was recorded and samples were taken. At the monitoring point, an area of about 22.5 km^2 is drained, with Ndolwa, draining an area of 8.4 km^2, and upper-Vudee draining 14.2 km^2. Separate samples were obtained from the two sub-catchments, just before the confluence during low flow. Major anions (Cl^-, F^-, SO_4^{2-}, HCO_3^-), and dissolved silica (SiO_2) and cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were analysed in the laboratory using an ion chromatograph and atomic absorption spectroscopy.

The hydrograph separation was based on a two-component hydrograph separation, which can be described by the following set of two equations.

$$c_T Q_T = c_S Q_S + c_B Q_B \tag{1}$$

$$Q_T = Q_S + Q_B \tag{2}$$

wherec_T is the concentration at sampling point [g m^{-3}], Q_T is the discharge at sampling point [m^3 s^{-1}], c_S is the concentration of the surface runoff (rainfall values assumed) [g m^{-3}], Q_S is the runoff contribution from the surface runoff [m^3 s^{-1}], c_B is the concentration of the sub-surface runoff [g m^{-3}] and Q_B is the runoff contribution from the sub-surface runoff [m^3 s^{-1}].

With a known concentration for sub-surface and surface runoff, the contribution from sub-surface and surface run-