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Interactive comment on "Identification of runoff generation processes using hydrometric and tracer methods in a meso-scale catchment in Rwanda" *by* O. Munyaneza et al.

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Referring to your helpful comments on our paper: Ref. No.: hessd-9-671-705, 2012 Title: Identification of runoff generation processes using hydrometric and tracer methods in a meso-scale catchment in Rwanda

We appreciated very much the critical review and constructive suggestions which are very useful for the improvement of the manuscript. All specific corrections suggested have been addressed in the revised manuscript. In the following, the most important changes are addressed point by point.

Major issue 1: We agree that we have to present in a revised manuscript the information on soils and geology in further detail to get an idea of infiltration and subsurface flow processes. This information of the dominating geology, soils (texture, type) and soil depths was included in the revised manuscript. The geology and soil properties were explained in the study area section as follow: The geology of the Migina catchment consists of very old granite rocks, overlain by substrates of grey quartzites and schists. These geological differences result in differences in topography. The site is mountainous with elevation ranging from 1375m a.s.l. at the outlet to 2278m a.s.l. at Mount Huye, which is located in the north-western part of the catchment. The soils in the valleys are often ferrallitic with a 50 cm thick humic A-horizon, which are sometimes buried below dynamically colluviating deposits (van den Berg and Bolt, 2010). The clay content of the A-horizon varies between 12% and 19% with hydraulic conductivities estimated between 1 and 10 m d 1 (Moeyersons, 1991). In the discussion section of the revised manuscript, more details were given regarding the soil characteristics in order to get a better idea of infiltration and subsurface processes: The high infiltration in the Migina catchment can be explained by a very high hydraulic conductivity as observed by van den Berg and Bolt (2010) using double ring infiltrometer tests in the same catchment (infiltration rate varied between 208 mm h−1 to 1250 mm h−1). The tests were conducted at locations where the land is used for agriculture. The rainfall intensities which are less than 17.6 mm h-1 are much lower than the infiltration rates (see Tables 1 and 2). They also measured maximum soil water content in the soil laboratory and found that the soil can hold up to 60-70% of water. This forms an important shallow subsurface water storage, which makes agriculture possible even in dry periods. Hence, this can lead to a subsurface runoff component contributing to the total streamflow. As expected, most of the plant available water content comes from the peat and clay layers which are also important for the growth of plants. In the Migina valleys, these layers appear at a depth of around 2 m (van den Berg and Bolt, 2010).

Major issue 2: The link between the two separated events (1-2 May 2010 and 29 April to 6 May 2011) and the remaining 11 events was further analyzed in Tables 1 and 2 and presented in Figure 2 to show the influence of pre-events on investigated events.

Major issue 3: The presentation of the isotopic fingerprint of the rainfall was improved in the revised manuscript to clarify the importance of that signature. We explained the fingerprint quite well on page 683, L26-27 and 684, L1-5. Also it is obvious in Figure 6 that the wet season rainfall is responsible for the light values of the groundwater and the baseflow. The isotopic composition of the rainfall is clearly different in the dry and wet season, and the wet season rainfall signature dominates the other water balance components (surface and subsurface water). Interestingly, the isotope values of the observed springs are not influenced by dry season rainfall values, as they all plot below the LMWL, show lighter isotope values than the amount weighted rainfall values of the wet season rainfall input. Thus, it can be concluded that the perennial springs in the area are recharged during the wet season.

Major issue 4: In the introduction, the increasing population density and importance of the resource water for the study area were focused on. These points were also picked up in the conclusions of the revised manuscript as follows: The outcomes of such an investigation are essential for sustainable water resources management and agricultural development to meet the high demands related to the rapid Rwandan population increase. The open question on how runoff coefficients were estimated was also addressed/clarified in the methodology of the revised manuscript. Annual runoff coefficient estimations were determined from Thiessen polygon representation of rainfall and continuous runoff records (Kadioglu, 2001). In this study, the runoff coefficient for each event was computed by dividing the total runoff volume by the total rainfall as recommended by Spiekma (1999). Rainfall measurements have been carried out by 13 manual rain gauges installed in the Migina catchment.

Major issue 5: The relatively small runoff coefficients between 16 and 40 % were discussed further and references to other recent research has been made. This was shown in the discussion part of the revised manuscript as follows: It depends on other factors such as the degree of slope, soil type, vegetation cover, antecedent soil moisture, rainfall intensity and duration. The runoff coefficient ranges usually between 1%

and 50% in cultivated catchments (FAO, 2006). Marchi (2010) did a study for extreme flash floods in Europe and found that the runoff coefficients of the studied flash floods are usually rather low with a mean value of 0.35. Moderate differences in runoff coefficient are observed between the studied climatic regions, with higher values in the Mediterranean region. Ley et al. (2011) found that the annual mean runoff coefficients in nested catchments of Rhineland-Palatinate, Germany, may range from 2% to 15% in the summer period, while during winter time they range from 5% to 56%. However, the current research was also done during the rainy season called Itumba in local language. That why it is concluded from the rainfall-runoff response analysis that runoff generation at the Kansi and Migina catchments is dominated by subsurface flows (see Tables 1 and 2).

Major issue 6: The paper was improved in the organization and structure, especially in the discussion section. The discussion part has been improved and linked to the objectives of the study. Sub-headers were included in the revised manuscript as follow: 5.1 Rainfall influence on runoff generation; and 5.2 Quantification of runoff components and processes in a meso-scale catchment. The introduction section was improved to make it clearer to the reader to better understand what is done for which research question. The conclusions section was also improved in the revised manuscript as follow: The results of this study demonstrated the importance of subsurface flows for stream flow generation in the study area. It shows the value of hydrological data collection over two whole rainy seasons using different tracers and hydrometric observations to understand dominant hydrological processes. Furthermore, it demonstrated the significance of considering spatial and temporal variations of rainfall in the hydrograph separations (Figs. 8 and 9); this is of greater importance in meso-scale catchments than in small headwaters.

Specific comments

Comment 1: P673, L19: The citations should be correct because the cited works are also referring to the rainy seasons as in our case study even if their study areas are in the semi-arid zone (Tanzania), a neighboring country of Rwanda.

Comment 2: P674, L19-20: The study objectives were reformulated at the end of the introduction in the revised manuscript and the working area was clarified. The objective of the paper is to quantify the runoff components and processes in a meso-scale catchment for two flood events occurred during the rainy season "Itumba" (March–May) over the period of 2 years, i.e. 1 to 2 May 2010 at Kansi sub-catchment and 29 April to 6 May 2011 at Migina catchment in southern Rwanda (Fig. 1). Specifically, the study emphasizes on the use of two- and three-component hydrograph separation mixing models for separating streamflow into surface and subsurface runoff and quantifying different runoff components under tropical conditions.

Comment 3: P675, L9-11: The sentence was rewritten in the revised manuscript and the coverage in percent has been given as follow: Land cover and hydrological soil group analyses in the Migina catchment show that the catchment is dominated by agriculture activities (92.5%) while forest occupy 5%; grass/lawn 2% and buildings cover 0.5% (Munyaneza et al., 2011).

Comment 4: P675, L12-14: The whole paragraph has been rewritten and sub-catchments were deleted in the revised manuscript. Therefore, only observed catchments were explained (Kansi and superior catchment) as follow. The investigated catchments in this paper are: Cyihene-Kansi catchment, further called Kansi sub-catchment (129.3 km2) and Migina catchment (257.4 km2) which covers the whole catchment including Kansi sub-catchment (see Fig. 1). The perennial Migina River drains into the Akanyaru River, which forms the border between Rwanda and Burundi. The Akanyaru River drains into the Kagera River, which flows into Lake Victoria and later generates the White Nile.

Comment 5: P681, L3-6: The pre event conditions were presented in Table 1 and 2 and in Figure 2 to show how they are much influencing the events. The sentence (P681, L1-3) was reformulated to make clear argumentation on why surface runoff is

dominated by subsurface components. Table 3 shows that the concentrations of most of the chemical components in surface water are related to the concentrations of water sampled from springs and piezometers during flood events. Only the opposite can be seen in dissolved silica (SiO2) and electrical conductivity (EC) concentrations. This indicates that surface discharge is dominated by subsurface runoff components during flood events in the Migina catchment.

Comment 6: P682, L11-15. The sentence was reformulated in the results part (Sect. 4.2) of the revised manuscript to avoid the transfer of plot scale observations to the meso-scale catchment size. The observed subsurface runoff dominance is also supported by the findings of Munyaneza et al. (2011) who showed that groundwater in the Migina catchment is very shallow (depth between 0.2–2 m) and infiltrated rain water can reach the groundwater quickly and contribute to subsurface stormflow and baseflow.

Comment 7: Page 685, L5: The volume was added and reported in the results part (sect. 4.1 on page 680, line 4) of the revised manuscript, where a maximum daily rainfall of 23.7 mm/d (6.1*106 m3) was observed. Figure 8a is clearly showing the rainfall amount and incremental mean values for the event of 29 April 2011 to 6 May 2011.

Comment 8: Page 686, L3-4: We agree that we cannot explain the infiltration in the meso scale catchment Migina with four point scale results done by van den Berg and Bolt (2010) using double ring infiltrometer tests at one small area in the head water of the Kansi catchment. But this can give an idea about the infiltration and subsurface processes in the areas used for agriculture in the catchment. Therefore, the finding should be referenced in the current study area with some revision. In the revised manuscript, units were provided in mm/h for comparison with rainfall intensity in this small area and more literature was added (See reply on major issue 1).

Comment 9: Page 686, L8-11: More literature was added in the revised manuscript as also suggested by reviewer #1 to make the context to the next sentences clearer (See reply on major issue 5).

Comment 10: Page 688, L22: We agree that the Tables 1 and 2 do not show clearly the origin of the hydrological compartments. Hence, the following sentence was deleted in the revised manuscript. It is apparent from the rainfall-runoff response analysis that runoff generation at the Kansi sub-catchment and Migina catchment is dominated by shallow groundwater (Tables 1 and 2).

Comment 11: Page 688, L24-25: The isotope analysis showed that all runoff components including baseflow are dependent on wet season rainfall. This is not surprising as the reviewer said but it is one of the expected results in this study which needs to be highlighted in the revised manuscript.

Comment 12: Table 3 and 4: The investigated period was added in the caption to show that the samples were taken during the complete two years. The caption became in the revised manuscript:

Table 3 Hydrochemical concentrations observed in the Kansi sub-catchment and Migina catchment during the investigated research period (from 1 May 2009 to 31 June 2011). n represents the number of samples. The entries in brackets represent the standard deviation values.

Table 4 Isotope concentrations observed at Kansi sub-catchment and at Migina catchment during the investigated research period (from 1 May 2009 to 31 June 2011). n represents the number of samples. The entries in brackets represent the standard deviation values.

On behalf of the authors, Omar Munyaneza, Kigali, Rwanda

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