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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Identifying residence times and streamflow generation processes using δ^{18}O and δ^{2}H in meso-scale catchments in the Abay/Upper Blue Nile, Ethiopia" *by* S. Tekleab et al.

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Reply to reviewer #1 comment Identifying residence times and streamflow generation processes using δ18O and δ2H in meso-scale catchments in the Abay/Upper Blue Nile, Ethiopia First of all we would like to thank the reviewer for his/her constructive comments and suggestions for improving the manuscript, which helped a great to deal to elevate it to publishing level. We have made several corrections and revisions based on the comments and suggestions indicated in subsequent sections and in the revised

manuscript. General comment: more interpretation of results is required e.g. when the different water lines are discussed, when the precipitation amount effect is discussed, when different moisture sources are discussed, when hydrological differences between the catchments are discussed. Also, the results of the hydrograph separation and the residence times deserve some more interpretation, especially with respect to stream-flow generation processes. Moreover, to improve the paper's readability, a thorough review of language and style is recommended.

Reply: We thank the reviewer for his/her constructive comments and suggestions. The paper tried to characterize and to identify the mean residence times and runoff components in a meso-scale catchment using stable isotope data of precipitation, springs and rivers water in a typical data scarce environment in the Upper Blue Nile basin. We fully agree on the comments and suggestions given by the reviewer to lift the paper to the level to which the current research undertakings are in the subject area. Many reasons could be mentioned for being the paper to be a base line paper. For instance, limited or no hydrological research activities in the catchment in the past, short record of data for stable isotopes, not well instrumented meso-scale catchments, and coarse resolution of isotope sampling to represent the spatial and temporal variation of isotope signals could definitely preclude adding one step in science. Nevertheless, in our opinion, the paper has contributed much for the region to begin with isotope methods for hydrological applications. We hope that similar studies in the near future will benefit and extend further based on this paper. Of course even in well instrumented hillslopes and small catchments deep understanding is still a challenge for hydrologists. (McGlynn et al., 2002). Therefore, based on the comments and suggestions given, several sentences, paragraphs, and further interpretation of results have been made. Moreover, many corrections on language and styles have been made throughout the revised manuscript.

Specific comment:

Comment: The identification of residence times is only a very small part of the paper

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at the very end (section 4.4). I am not sure whether this justifies the current title.

Reply: We agree on the comment given with regard to the title of the manuscript that identification of mean residence times are described in one section might not represent the whole objective of the paper. Therefore, we amended the title of the manuscript in the revised manuscript.

Comment: p. 34, l. 15: I would recommend that the authors choose one of the terms (main rainy or summer, little rainy or spring, dry or winter) and stick with it throughout the whole manuscript. So far, the terms are used interchangeably and this adds some confusion here and there.

Reply: We thank the reviewer for the correction. Consistently throughout the manuscript we have made correction to use the terms (main rainy or summer, little rainy or spring, dry or winter) as it is described in the abstract.

Comment: p. 34, l. 19-21 and l. 24-28: You talk about residence times at the end of one paragraph(19-21), then you start a new one talking about hydrograph separation (22-24) and then you go back to residence times (24-28). Better finish the residence time part before reporting on hydrograph separations.

Reply: Based on the suggestion given, sentences about residence times are re-written, and corrections have been made in the abstract section.

Comment: p. 35, l. 1: Does 'suggest' mean that these catchment management measures are Ongoing or recommended?

Reply: Catchment management measures are recommended.

Comment: p. 35, l. 21: What is the East African meteoric water? Some details about its origins and characteristics would be helpful for comparison.

Reply: We thank the reviewer for the comment. The characteristics of the East African meteoric water line, derived from the Global Network of Isotopes in Precipitation (GNIP)

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stations, e.g. Dar es Salaam in Tanzania showed a lower isotopic composition than the Ethiopian Addis Ababa station within a similar altitude range ∼2360 m a.s.l. For stations in East Africa the moisture for the precipitation originates from the Indian Ocean at both rainy seasons (Rozanski et al., 1996). In contrast, westerly low-level winds coincide with precipitation events during the summer rains in Ethiopia June–September and indicate a westerly moisture source. Moisture from this region is likely recycled water via transpiration and has a higher isotopic value (Levin et al., 2009). It is now reported clearly under the introduction section.

Comment: p. 35, l. 23- p. 36, l. 2: Sentence structure is awkward and unclear.

Reply: The sentence is now clearly written.

Comment: p. 36, l. 3: Why do you use 'nevertheless' here?

Reply: We deleted 'Nevertheless' and the beginning of the sentence is now corrected in the revised manuscript.

Comment: p. 36, l. 20: You should mention the fact that time-invariant residence times are naturally unlikely to exist in real-world catchments and that there is quite some newer literature (in the last 2-3 years) that tries to tackle these assumptions by introducing methods to determine time-variable residence times (Botter, Hrachowitz, Heidbüchel, van der Velde).

Reply: We thank the reviewer for the suggestion to include the new scientific literatures with respect to time variable mean residence time estimation. The citation is now included in the introduction section of the revised manuscript.

Comment: p. 39, l. 9: What about evaporation within the bottle? A 10 liters canister leaves a large air-filled volume.

Reply: To avoid the evaporation from the canister we have devised two mechanisms. One of the mechanisms is that the plastic canister has been put below the ground surface so as to avoid evaporation due to direct heating the external part of the canister.

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Secondly, the canister was modified based on the suggestions from the IAEA Water and environment newsletter Issue 16, November 2002. A plastic hose fitted on the top of the canister prevents by the inflow of the first precipitation water further contact of water moisture with the atmosphere.

Comment: p. 41, l. 3-6: This method is unclear. Please rephrase.

Reply: The method is now clearly re-written in the revised manuscript.

Comment: p. 41, l. 20: Using the weighted mean isotopic composition of precipitation is problematic. Since the isotopic composition of precipitation events within a month can vary widely from event to event, I would recommend using a different end-member for every event and only accumulate the event/pre-event fractions afterwards. This could change your results significantly and still would give you a much more robust estimation of these fractions.

Reply: We agree that the isotopic composition within a month varies considerably from event to event. However, our precipitation sample is a bulk sample for the events collected together on biweekly basis. Thus, we made the amount weighted isotopic composition on monthly basis.

Comment: p. 43, l. 3: This is the one and only time you mention 'transit time' in you manuscript. see that you assume that residence time and transit time are the same, but still I would stick with one of the terms.

Reply: We thank the reviewer for the comment to use consistent terminology. We stick to the residence time throughout the manuscript.

Comment: p. 44, l. 4: Maybe rather name this section 'Meteoric water lines' or just 'Water lines' instead of 'Meteoric water', since you will be discussing more 'meteoric water' in the following section.

Reply: We prefer to name the section as 'Meteoric water lines'.

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Comment; p. 44, l. 9: Please discuss the effect of evaporation of falling rain drops for the deviation.

Reply: Figure 3 illustrate the relationship between δ18O and δ2H composition. The effect of evaporation of falling rain drops are insignificant to deviate from the global and local water lines. Had it been more deviation it is possible to plot the local evaporation line (LEL). However, for the whole of the water samples the effect of evaporation either from precipitation, river water or springs are minor to be reflected in the figure.

Comment: p. 44, l. 13-16: Unclear, please rephrase.

Reply: The sentence is now rephrased in the revised manuscript.

Comment: p. 44, l. 22: 'heavy delta18O values' is technically incorrect. Use a consistent terminology regarding isotopes. For example: 'enriched in the heavy isotope' or 'less negative delta18O values' instead of 'higher delta18O values'.

Reply: We thank the reviewer again for raising to use consistent terminology with regard to isotopes. We agreed to use consistent terminology 'less negative delta 18O and 2H' and more negative delta 18O and 2H values throughout the document in the revised manuscript.

Comment: p. 45, l. 8: entails?

Reply: We have rephrased the sentence in the revised manuscript.

Comment: p. 45, l. 8: Do not write: 'decrease the isotopic composition'. That does not meananything.

Reply: We thank the reviewer for the comment. Throughout the revised manuscript the expression is changed to 'more negative value of isotopic composition'.

Comment: p. 45, l. 8-12: Do you have any clue why the 3000 m station always has less negative values than the 2400 m station? This is contrary to what you say in this paragraph and you should discuss it.

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Reply: The 3900 m station, which is Fana Choke, is the station at the highest altitude among the examined stations. Sample analysis of this station is always towards more negative values of delta 18O and 2H. These results are anticipated due to the fact the high altitude and meteorological settings such as more humidity, less temperature, and high amount of rainfall at this particular station could results in more negative delta values.

Comment: p. 45, l. 13: What relationship did you find? Describe it with words - that makes reading and understanding much easier.

Reply: The relationship between the isotope composition with the monthly rainfall amount and mean monthly temperature values shows that the amount effect plays a more important role to change the isotope values than the temperature effect. The results for the amount effect show that moderate coefficients of determination R2 vary from 0.29 to 0.68 for a linear regression model, and R2 values vary from 0.74 to 0.76 for the multiple linear regression model for the Chemoga and Jedeb catchments.

Comment: p. 46, l. 10: Again, some more details on these 'multiple moisture sources' and the'local meteorological processes' would be helpful.

Reply: We thank the reviewer for the comment. The details about multiple moisture sources and local meteorological processes are now described in the revised manuscript under the separate section 4.3.

Comment: p. 46, l. 12-27: This needs better structure to make it clearer to the reader. Also, you see opposing trends in the spring with FC becoming more negative and YW becoming more positive.

Reply: We thank the reviewer for the comment. Accordingly we have restructured the sentences in the revised version of the manuscript under the same section. Moreover, it is correct that at FC the isotope are consistently more negative values and at YW less negative or more positive values. These isotopic values are anticipated and reveal

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the effects of altitude and amount on the isotopic variation.

Comment: p. 47, l. 8: But you said that the amount effect is more important than the temperature effect. Unless higher elevations also receive more precipitation, it is hard to tell whether the recharge areas for the springs are located at different altitudes.

Reply: In the study area where the isotope and precipitation locations are situated in different altitude range varies from 2190-3993 m a s.l. Consequently the highest altitude location, Fana Choke always has high amount of rainfall than the rest of the locations. Moreover, as a rugged topography and mountainous area the orographic lifting is also responsible for receiving high amount of rainfall in the Fana Choke station. Therefore, we infer that similar isotopic signature of the Rob Gebeya and Debre Markos springs is likely due to common recharge area, and the Yewla on the lower altitude having less negative delta values.

Comment: p. 47, l. 9: What is the 'mean isotopic variation'?

Reply: The mean isotopic variation at the three spring locations ranged from -0.6 to 5.5‰ for δ2H and -2.1 to -0.7‰ for δ18O.

Comment: p. 48, l. 20-24: But neither the Atlantic Ocean nor the Mediterranean Sea is on the map shown in Figure 11.

Reply: We thank the reviewer for the comment. The map showing the trajectories of air mass from different sources are now updated. Thus the trajectories are indicating the Atlantic and Mediterranean Sea.

Comment: p. 49, l. 15: What do you mean by 'reveal the variation in catchment storage'? Please elaborate.

Reply: Comparing the isotope signature in the Chemoga and Jedeb catchments, the signature in the Jedeb catchment is relatively damped as compared to Chemoga catchment. This damping behavior indicates the groundwater storage in the Jedeb catchment is more than Chemoga catchment. The three years field visit also supported

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that during the dry season in the Jedeb catchment the flow was sustained while in the Chemoga catchment it was hardly find the dry season flow in the river. Thus, the two catchments have different storage capacity. This in turn might be related to the differences in hydrologic behavior.

Comment: p. 49, l. 15-17: If you mention this water balance study here, it would be good to relate some of its results to the results from this isotope study.

Reply: The results of the annual water balance study (from the plot of annual evaporation ratio to aridity index in a Budyko (1974) curve) show that Chemoga catchment has a higher evaporation ratio than the Jedeb catchment. Consequently, even though the Chemoga catchment has a larger catchment area (358 km2) the discharge amount is lower than in the Jedeb catchment (296 km2). Furthermore, the water balance study indicate more surface runoff generation in these catchments, which is in line with the results of the seasonal hydrograph separation using stable isotopes.

Comment: p. 49, l. 18-28: This paragraph is unclear. Please rephrase.

Reply: We thank the reviewer for the comment. The paragraph is now rephrased in the revised manuscript under the same section.

Comment: p. 50, l. 11-16: Unclear. Please rephrase.

Reply: The paragraph is now rephrased in the revised manuscript.

Comment: p. 50, l. 20: What are these 'visual observations'?

Reply: The visual observations are what we have seen in the field. Surface runoff generation starts immediately after the rainfall event in agricultural fields, in grazing lands and on bare lands. The existed gully formation as a result of severe erosion from different land use also corroborate the results of the isotope study, which shows dominance of the event water proportion in these catchments.

Comment: p. 51, l. 12-17: This nested sentence is unclear. Please rephrase.

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Reply: The sentence is now rephrased in the revised manuscript.

Comment: p. 51, l. 18- p. 52, l. 13: The section on uncertainty analysis should be rewritten. It contains nested sentences and lacks clarity. What does it mean when you say that'This lower average uncertainty term accounted for +-0.46 for Chemoga? +-0.46 of what exactly? Uncertainty, variability, error? From which sources does the error in hydrograph separation originate? Can you give some more information?

Reply: The section of the uncertainty analysis is re-written in the revised manuscript. The average uncertainty term +- 0.46 means, the total average error propagation over the investigation period for the event, pre-event, and streamflow at 70% using standard deviations(δ) multiplied by t values from the Student's t distribution. From the uncertainty analysis the larger percentage of error was propagated from the event component. As pointed by Genereux, (1994), the largest error propagation in the hydrograph separation is stem from the component accounted for greater proportion of the mixture (i.e. total streamflow). In our case the event component was accounted more than half of the total streamflow.

Comment: p. 53, l. 9-11: Direct comparisons with other similar meso-scale catchments are definitely possible and also scientifically interesting. Especially when different climatic settings, soil types, geologies and land cover properties change the residence times.

Reply: Discussion of results with other similar meso-scale catchments has been included in the revised manuscript under section 4.5.

Comment: p. 53, l. 20: What are these local meteorological settings?

Reply: The local meteorological settings are localized precipitation, air temperature, wind speed, and relative humidity.

Figures:

Comment: Figure 1: A different color scheme with less extreme colors would be better

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for the elevation map. Also use bolder labels in general and different sizes (or fonts) for the catchment names.

Reply: Based on the suggestion figure 1 is corrected.

Comment: Figure 3: The order of the legend entries is mixed up. Group all the springs and streams together and move the water lines to the end. Maybe add three trend lines for Q, S and P and remove the black marker outlines. You could also order the marker colors by elevation and give the LMWL a different color than the one from Addis Ababa.

Reply: According to the comment correction has been made on figure 3.

Comment: Figure 5: For easier comparisons you could make just 2 panels – one with all the 18O data and the other with all the 2H data.

Reply: Figure 5 is now corrected.

Comment: Figure 11: This is very small. Maybe insert a window where you zoom into one of the rainy seasons to show some detail.

Reply: Following the suggestion details about the summer season are shown in a separate window.

Technical Corrections:

Comment: p. 34, l. 12: Sudd or Sud?

Reply: It should be Sudd and is corrected in the revised manuscript.

Comment: p. 34, l. 13: 'likely' or 'potential'?

Reply: 'Likely' is now replaced with 'potential'.

Comment: p. 34, l. 16: 'affected by the amount effect' sounds awkward.

Reply: Correction has been made in the revised manuscript.

Comment: p. 34, l. 16: 'to a lesser extent'

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Reply: The sentence is now re written in the revised manuscript.

Comment: p. 35, l. 19: affected

Reply: ‘Effected’ is replaced by ‘affected’.

Comment: p. 36, l. 7: ‘utility’ and ‘use’ are mixed up in this sentence.

Reply: The sentence is corrected.

Comment: p. 36, l. 17: missing parentheses for the citation.

Reply: We do not think that parenthesis is required for the citation.

Comment: p. 36, l. 28: ‘. . .. . .in the two adjacent meso-scale headwater. . ..’

Reply: The sentence is restructured in the revised manuscript.

Comment: p. 37, l. 3: ‘. . .tributaries of the Abay/Upper Blue Nile,. . ..’ (Without basin)

Reply: Accordingly we made the correction.

Comment: p. 37, l. 14: ‘. . .oats and potato. . ..’

Reply: The initial letters are changed in to lower case oats and potato

Comment: p. 38, l. 5: 2011 not 2001!

Reply: 2001 is replaced with 2011.

Comment: p. 38, l. 10-11: You use ‘over the same period’ twice here.

Reply: The sentences are rewritten in the revised manuscript.

Comment: p. 39, l. 7: remove ‘locally’

Reply: The word locally is removed.

Comment: p. 41, l. 8: ‘. . ...neither as surface nor as subsurface. . .. . .’

Reply: The sentence is corrected in the revised manuscript.

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Comment: p. 41, l. 15: ‘At the same time. . .. . .’

Reply: The sentence is corrected.

Comment: p. 45, l. 26: It should read ‘. . .. . .+ 2.093T +. . ..’

Reply: The number is now corrected.

Comment: p. 46, l. 5: ‘. . ..presents. . .. . .’

Reply: Correction has been made in the revised manuscript,

Comment: p. 48, l. 1: ‘shows that’ instead of ‘reflects’.

Reply: Correction has been made in the revised manuscript.

Comment: p. 48, l. 9: Delete ‘results of the’.

Reply: Correction has been made in the revised manuscript

Comment: p. 49, l. 8: Delete ‘While’.

Reply: Correction has been made in the revised manuscript.

Comment: p. 50, l. 4: ‘. . ..: reveals that the. . ..

Reply: Correction has been made in the revised manuscript.

Comment: p. 50, l. 18: ‘This implies that the new water component is generated via surface. . ...’

Reply: Correction has been made in the revised manuscript.

Comment: p. 50, l. 23: ’. . ..high percentage . . .. . . is due to the low infiltration’.

Reply: Correction has been made in the revised manuscript.

Comment: p. 51, l. 9-12: ‘Although the application of the method to semi-arid catchments in Africa is limited . . ... the outcome from this research also suggests that. . ..’.

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Reply: Correction has been made in the revised manuscript.

Comment: p. 52, l. 21: Delete ‘results of’.

Reply: Correction has been made in the revised manuscript.

Comment: p. 52, l. 26: agriculturally.

Reply: Correction has been made in the revised manuscript.

Comment: p. 53, l. 6: Delete ‘quantification of’.

Reply: Correction has been made in the revised manuscript.

Comment: p. 54, l. 8: ‘. . ...were used for the first time. . ...’

Reply: Correction has been made in the revised manuscript.

References:

Genereux, D.P.: Quantifying uncertainty in tracer based hydrograph separation. Water Resources Research, 34 (4): 915-919, 1998.

Levin, N.E., Zipser, E.J., and Cerling, T.E.: Isotopic composition of waters from Ethiopia and Kenya: Insight into moisture sources for eastern Africa. Journal of Geophysical Research., Vol. 114, D23306, doi: 10.1029/2009JD012166, 2009.

McGlynn, B. L., McDonnell, J. J., and Brammer, D. D.: A review of the evolving perceptual model of hillslope flowpaths at the Maimai catchments, New Zealand, J. Hydrol., 257, 1 –26, 2002.

Rozanski, K., Araguas-Araguas, L., and Gonfiantini, R.: Isotope patterns of precipitation in the east African region, In: Johnson, T.C., Odada, E. (Eds.), The Liminology, Climatology and Paleoclimatology of the East African Lakes, Gordon and Breach, Toronto, pp. 79-93, 1996.

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