Reply to comments from Anonymous Referee #2.

General Comments

The manuscript attempts to quantify seasonal variabilities in groundwater discharge in an extensive irrigation watershed using H, O, and Sr isotopes. conducted point- and watershed-scale observations of surface water, soil water, groundwater, and ponded water in rice paddies and examined changes in these isotopic compositions. They conclude that the ratios of groundwater to the stream was in the range 7–86% during the irrigation period and 38– 66% during the non-irrigation period. The use of Sr isotopes showed better results that those of stable water isotopes. The manuscript contains some useful material, however in its current form the manuscript is not publishable. It seems particularly apparent given the amount of time the manuscript spends describing the measurement results itself. While no quantitatively evidence to support their assumptions, e.g. the water isotope diagram can not provide direct evidence. And despite the length there are several statements in the technical description which need to be clarified as they indicate some further analysis is required to confirm the results.

[Response]

We thank the reviewer for his/her time towards reading our manuscript and providing thoughtful comments. Our responses to the comments are as follows.

Major comments:

1. I don't find the new insight from this paper. Since Sr isotopes is less fractionation, it is well known that the use of Sr isotopes has the higher potential to aid in quantification of temporal variations in groundwater discharge.

[Response]

In a previous manuscript, we concluded that Sr isotope is more stable in terms of space and time than water isotopes and has higher discriminating power for quantifying groundwater discharge. As the reviewer suggested, this is consistent with previous findings. However, to our knowledge, studies that aimed to quantify groundwater discharge using the stability of Sr isotopes in groundwater have been quite rare. The groundwater table of the study watershed drastically changes between irrigation and non-irrigation periods (see Figure 2 below), thus the groundwater discharge from the regional aquifer significantly differs. This is the first study that illustrated the seasonal variation of groundwater discharge using Sr isotopes. We also pointed out it should be noted that Sr isotopes may vary through water-rock interactions and might overestimate the groundwater contribution to streams, especially when groundwater discharge does not dominate the hyporheic exchange rate. We updated sections 4.1 and 4.2 to verify the robustness of the endmembers and the consistency of estimated groundwater ratios in the stream using two isotopes. We also added chloride concentration to corroborate our conclusion. We would, therefore, conclude that the combined use of multiple tracers, including Sr and water isotopes and geochemical tracers, is recommended for examining the water mixture.

[Changes in the manuscript]

To reflect all these changes, we moved all the results regarding the endmember analysis from the discussion in the previous manuscript. In the revised manuscript, we also expanded the discussion, describing the use of multiple isotopes and geochemical tracer for understanding the hydrological cycle.

2. The manuscript is not straightforward, and the results are difficult to understand. For me, it is better to show the sampling locations in more detailed way. I can not find where is the location of Br1- 23. And where is the upstream and downstream mentioned in the manuscript. Also, please give the detail information about sampling date. This is extremely important for stable water isotope study. If surface water, soil water, groundwater, and ponded water in rice paddies are sampling in different days, the authors should make sure they are not change significantly in temporal scale.

[Response]

The location and date of sampling are now specified in the revised manuscript. To understand the relationship among the sampling locations, we integrated Figures 1, 2 and 3 into one figure. For Figures 2 and 3 in the previous manuscript, we added the location of the bridges along the Gogyo River (sampling location of stream water) and the upstream and downstream.

The sampling was conducted within 3 consecutive days of the survey, during the period no precipitation was recorded. In addition, the effect of precipitation is considered to be negligible because cumulative precipitation before the survey was less than 20 mm.

As the reviewer pointed out, the stable isotopes of water show temporal variation, and the degrees of the variations are the largest in precipitation, followed by ponded water in rice paddies, soil water, and groundwater. The point-scale survey of this study confirmed that the variation of soil water and groundwater were less than those of ponded water in rice paddies. The scope of this study is to examine the interactions between streamflow and groundwater, rather than investigating changes in the stable water isotopes through irrigation, evaporation and percolation in rice paddies. For this objective, we showed the seasonal variations of stable water isotopes in groundwater and identified suitable endmembers that have the least seasonal variations. Indeed, the temporal variations in stable water isotopes may induce uncertainties in the estimated groundwater discharge and we will address this issue in our ongoing research.

[Changes in the manuscript]

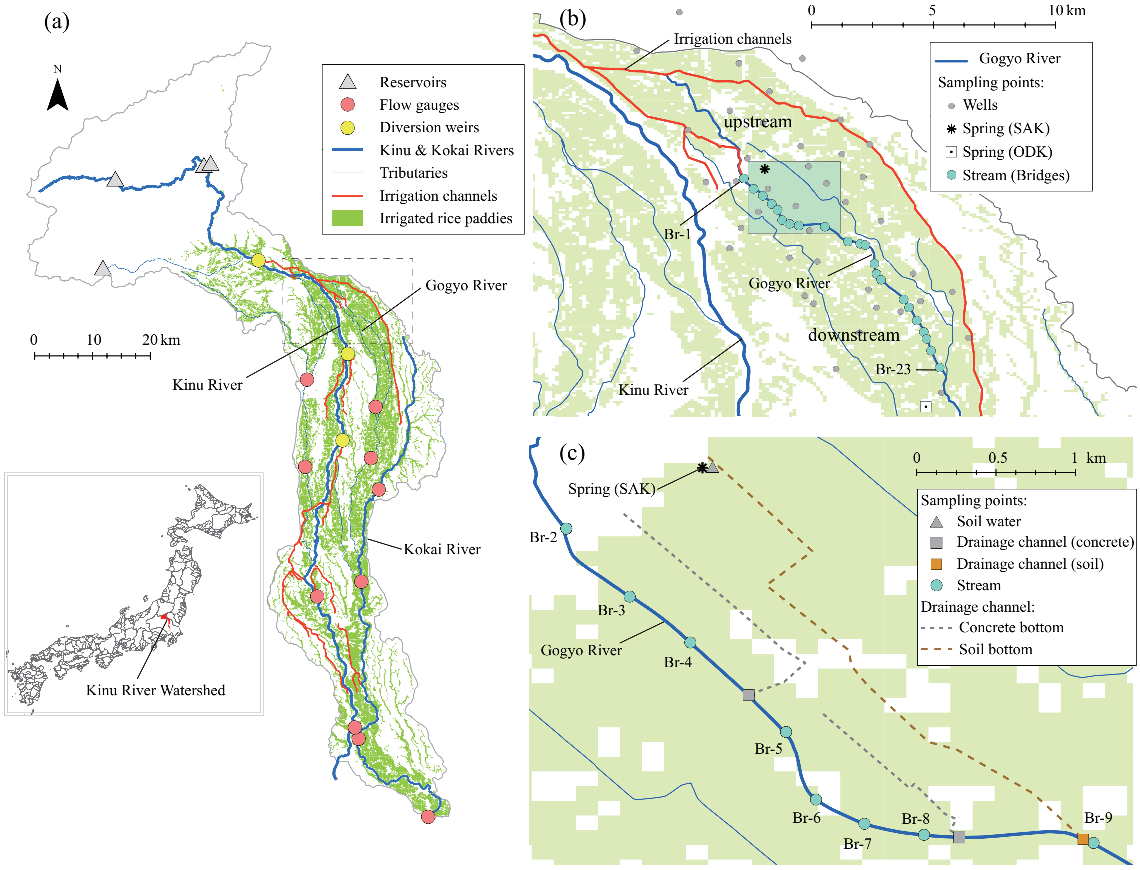

Figure 1 Overview of the study watershed: (a) Kinu river watershed, (b) sampling location in the Gogyo river watershed. Shaded area is depicted in (c), (c)

The groundwater and surface water sampling were conducted during three consecutive days in each of the irrigation and non-irrigation periods (21–23 June 2016 and 12–14 October 2016). To minimize the effect of precipitation on surface water sampling, we determined the sampling date in which cumulative precipitation for one week before the sampling periods were less than 20 mm. The average temperature during the surveys were 22 and 15°C for the irrigation and non-irrigation periods, respectively.

3. Ponded water isotope in rice paddies indeed showed large spatial variability. The inflow side and outflow side will show large differences. I don't know whether the authors consider this or not. To get an average value, I think it need special treatment.

[Response]

As we replied to the previous comment, numerable studies showed that the temporal variation in stable water isotopes was large. In addition to the temporal variation in precipitation, the effects of kinetic fractionation in rice paddies would increase the variabilities.

Gehrels et al. (1998) observed $\delta^{18}O$ in soil water at different depths and found that the values near the ground surface varied in time, reflecting temporal variations in recharged water, while it converged with depth to the average of the variation. From the point-scale survey, we showed that the water isotopes obtained at the depth of 1.0 and 1.5 m were almost similar and were close to the values of the average of two water samples obtained in the paddy fields with different irrigation rates. Our observation was consistent with the findings of Gehrels et al. (1998) and suggested that the water isotopes in the soil can average the variations in the isotopic compositions from rice paddies.

The values of the water isotopes obtained at the soil water sampling plot, which is close to the apex of the fan, were similar with the values obtained at the spring, ODK, which is located at the toe of the fan. This can be explained by the buffering effect of the aquifer.

[Changes in the manuscript]

(previous manuscript) While the stable isotopes in ponded water changed in many ways, percolation appeared to have little effect on water isotopes in subsurface flow, …

(revised manuscript) While the stable isotopes in ponded water changed in many ways, the isotopic composition appeared to converge to the average of the surface water variation through percolation.

(previous manuscript) This lower variability suggests that spring water isotopes were spatial and temporal averages.

(revised manuscript) This lower variability suggests that spring water isotopes reflected the buffering effects of the regional aquifer.

Gehrels, J.C., Peeters, J.E.M., De Vries, J.J., Dekkers, M. (1998) The mechanism of soil water movement as inferred from ^{18}O stable isotope studies, Hydrological Sciences Journal, 43(4), 579-594.

4. The most important thing is neglecting the effect of precipitation. Please plot out the precipitation during the sampling period. Precipitation will definitely change all the results.

[Response]

As described in the response to the first comment, we added a description of the weather conditions during the sampling period, and it was suggested that the direct effects of precipitation on the surface water samples were negligible. The water isotope of the precipitation was plotted in Figure 4(a). The red dashed line in Figure 4(b) indicates the direction for the precipitation plot. We added an inset to Figure 4(b) that shows all the sample plots including the precipitation.

The precipitation apparently affected surface water (e.g., Sr isotopic compositions of water in the rice paddies through dilution); however, the temporal variations in precipitation would not change the values of Sr and water isotopic compositions in the groundwater because of large buffering effect of the aquifer. This study aims to examine the relationship between streamflow and groundwater. Thus, we would argue that this comment from the reviewer missed the point we are trying to make.

[Changes in the manuscript]

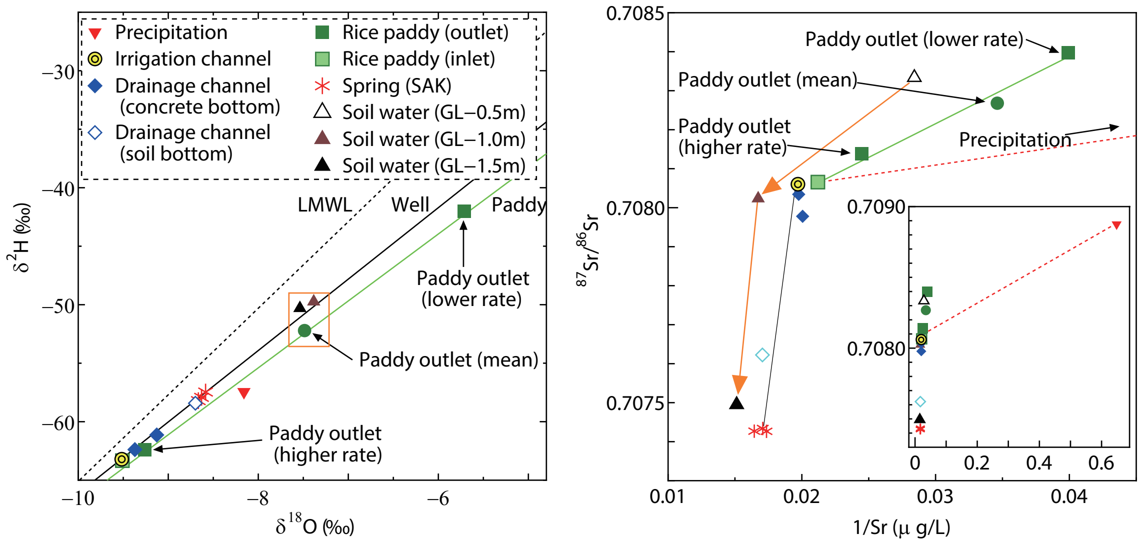

Figure 4 Water isotope diagram and $^{87}Sr/^{86}Sr$–1/Sr diagram for the point-scale survey.

5. The two endmembers partitioning method is good but neglecting the recharge process. This may be important for irrigation period. Large portions of irrigation water may recharge regional aquifer. Any idea or evidence?

[Response]

This study focuses on how the recharge from rice paddies may or may not affect the isotopic compositions of regional aquifers. To address this point, we conducted the point-scale survey and examined how Sr and water isotopic compositions change through percolation. We found that Sr isotopes change relatively within a short time through water-rock interactions and reached an equilibrium to the Sr isotopic composition of the lithology. On the other hand, the water isotopes in the recharged water was significantly affected by evaporation at rice paddies and change the groundwater isotopic compositions. We would argue that the recharge processes were not neglected, but they are rather included as the central topic of this study.

[Changes in the manuscript]

Added an explanation in the 'Study watershed' (2.1.1) and a figure depicting the seasonal variations in precipitation and depth to the groundwater table (see Figure 2, response to the following comment).

To illustrate an overview of water balance, we added a figure depicting seasonal variations in precipitation and groundwater table of the watershed. The figure includes the duration of irrigation for rice paddies (from April 15 through August 31) to indicate that the regional aquifer receives a substantial volume of recharge from ponded rice paddies and the groundwater table increases by about 2 m during the irrigation period.

Indeed, large portions of irrigation water recharge the regional aquifer and increase the regional water table by approximately 2 m. Consequently, the regional aquifer becomes the major source of groundwater discharge during irrigation seasons.

6. To give some quantitative conclusions from the isotope experiment, I suggest the authors should at least discuss the result with water balance components (precipitation, ET, irrigation, flow rates in rivers, groundwater table fluctuations, etc.) at the specific studied area. For instance, the authors can estimate the irrigation water based on the local irrigation schedule and the cultivated area. Currently, the authors only present the peak flow rates for the whole diversion weirs (71 m^3/s), it is hard for us to link this to your experimental results.

[Response]

Along the reviewer's comment, we have added the following explanation to illustrate the characteristic hydrological cycles of the study watershed (Figure 2). As depicted in Fig. 2, the groundwater table is raised by about 2 m at the onset of the irrigation (early May).

The streamflow during the irrigation period fluctuated as depicted as 'Observed streamflow' in Figure 10 and 11 in the previous manuscript. As shown in Fig 10 (see below) and the description in the previous manuscript, it is very difficult to grasp the water balance from the streamflow data alone because there were substantial number of inflow and outflow channels to the stream: '*We measured the rates of lateral inflow at 30 channels (drainage from surrounding rice paddies) and of outflows at 22 channels (diversions from stream to paddies)*'.

Because these two points would be important background why we conducted this study, we added descriptions to clarify them.

[Changes in the manuscript]

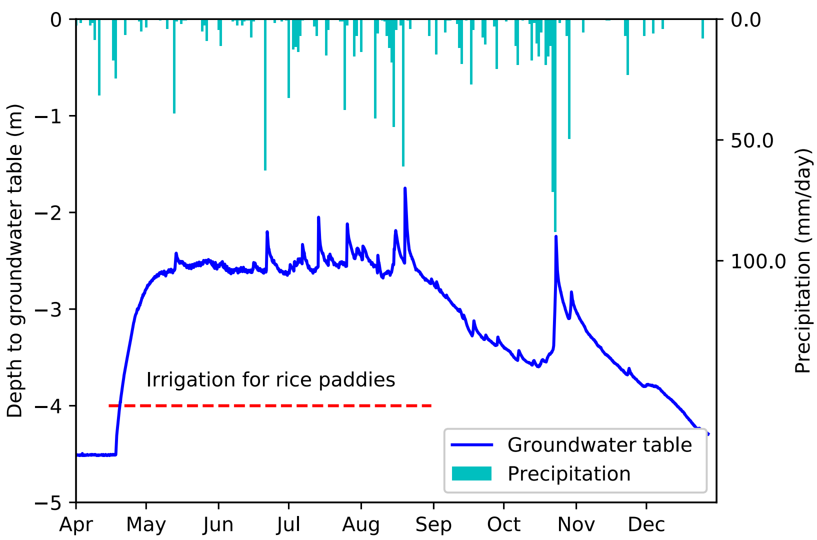

Figure 2 Seasonal variations in precipitation and depth of the groundwater table.

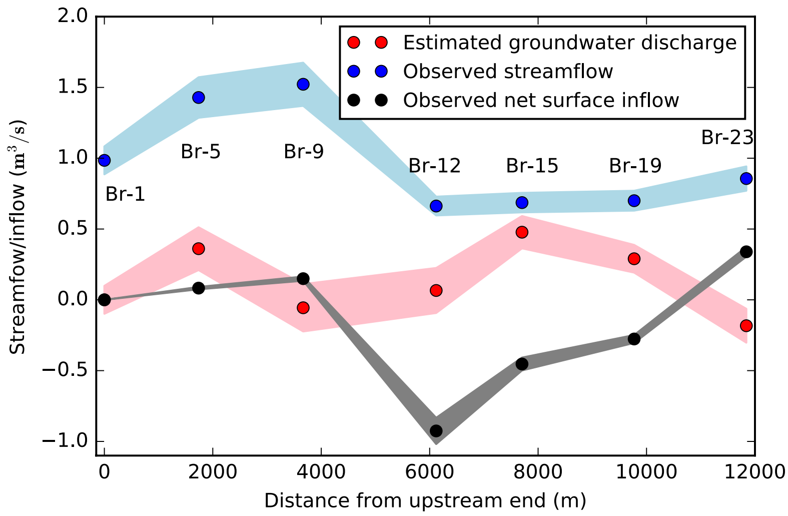

Figure 10 Estimated groundwater discharge to stream based on the observed water balance during irrigation period.

Minor comments:

Line 24 p5: The – the

The error has been corrected.

Line 25 p6: water table was 1.67 m — this is confusing. Do you mean groundwater depth?

Thank you for pointing this out. The depth has been specified: the groundwater depth was 1.67 m from the ground surface.

Line 21 p9: Usually observation error is not portable, given the data features at different basins are quite different. Moreover, the reference you cite is from 1963, now we have more accurate and convenient method to measure the flow rate.

[Response]

There are several other papers that show observation errors in stream flow measurement. For example, McMillan et al. (2012) summarized uncertainties from the extensive review of the streamflow measurements; and the typical errors in streamflow measurement are 50–100% for low flows, and 10–20% for medium to high flows. Hence, we would argue that our assumption for the errors in stream flow measurement of 15% is reasonable.

[Changes in the manuscript]

McMillan et al. (2012) summarized uncertainties through an extensive review of the streamflow measurements, and typical errors in streamflow measurement are 50–100% for low flows, and 10–20% for medium to high flows.

Lines 6, 8 in p11: leave a space after ‰

A space has been inserted.

Line 7 p12: duplicated ,

The duplication has been eliminated.

Line 21 p13: The – the

The error has been corrected.

Line 26 p13: please use endmember or end member consistently in the paper.

We have ensured consistent use of ‘endmember’ the revised manuscript.