Quantitative evaluation of the effect of paddy irrigation on river flow regimes using water stable isotopic ratios

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In a basin with a large area of paddy fields, generally, abundant water is taken from the river for irrigation. On the other hand, a considerable amount of water returns the river from paddy fields especially in the irrigation season. Consequently, paddy agriculture can significantly affect river flow regimes. Recently, farmland area has been decreasing in Japan. It might lead to changes in river flow regimes. However, the method to quantitatively evaluate the effect of paddy agriculture on river flow regimes. In this study, we tried quantitative evaluation of the ratio of the return flow from paddy field to river flow using water stable isotopic ratios (δ D and δ^{18}O) as a case study in the Chikusa River Basin in Hyogo prefecture, Japan.

On-site surveys were conducted in 3 sub-basins (the Sayo and the Shibumi tributaries and the upper stream) of the Chikusa River Basin once or twice a month from April to November in 2019 (totally 10 times). The land surface in each sub-basin is mostly covered by forests and paddy fields. On each survey, on-site water quality measurement (temperature, pH, ORP, EC, DO, and TDS) and water sampling were carried out at each observation point. For the obtained water samples, δ D, δ^{18}O, minor elements, dissolved ions, COD, TOC, TN, and TP were analyzed.

Additionally, the surface water in some paddy plots (only when ponded) were sampled averagely 2-3 times a week from July to September 2019 by 6 farmers. We installed bottles with a funnel and an evaporation preventer at 5 points along the Chikusa River from upstream to downstream and collected rain water stored in them once a month. Water stable isotopic ratios of these water samples were measured. For data analysis, we also used the δ D and δ^{18}O data of branch streams in the Sayo and the Shibumi River sub-basins and snowpack around the most upstream of the Chikusa River obtained by another research project from 2015 to 2019.

We obtained results and findings as follows: 1) Isotopic ratios (δ D and δ^{18}O) of headwaters in this basin were plotted apparently far away from the local Meteoric Water Line (LMWL) and their distances became larger according to the altitude of the sampling point. Isotopic ratios of snowpack were plotted much further away from the LMWL to the same direction as those of headwater. From these results, we concluded that the headwaters are influenced by snowmelt water all through the year. 2) Isotopic ratios of all water samples were plotted almost in a straight line on a δ -diagram. Only the plots of headwaters were distributed at one end (isotopically lighter side) and almost only those of paddy surface water at the other (heavier side). All the plots of river waters were distributed between them. While the fluctuations of isotopic ratios of headwaters over period were small, those of paddy surface water were relatively larger. 3) In each river, even in river reaches with almost no paddy field area, river water became slightly heavier as it flowed down. Meanwhile, in river reaches with considerable paddy field area, the change was significantly larger especially in the irrigation season. It was presumed that this difference occurred by the return flow from paddy fields. In the non-irrigation season, the difference became smaller. 4) At the confluence point of the Chikusa River and each of tributaries, mixing ratios of both river waters were calculated by comparing the isotopic ratios of river waters before and after the confluence. The mixing

ratios almost agreed with the values calculated by using other indices such as EC, metal ions, etc. 5) The percentage of return flow from paddy fields in river flow was estimated using isotopic ratios of headwater (considered the change in flowing down) and paddy water. In the case of the Sayo River, the percentage accounted for 15 % in irrigation season, which was more than 20 times of the paddy area ratio to the basin area.

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