# Applicability of $^{87}Sr/^{86}Sr$ in examining surface-groundwater interactions in extensively irrigated paddy watersheds

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Repeated cycles of water diversion from and return flows to main channels have substantial impacts on the flow regimes of watersheds containing extensive areas of irrigated paddy fields. Numerous studies have attempted to decipher the hydrological processes in such irrigated areas; however, surface-groundwater interactions hinder the understanding of the fate of the irrigation water. Although the stable isotopes of water, deuterium and $^{18}O$ are the major tracers used to decipher hydrological processes of watersheds, these isotopes cannot be used to track the fate of irrigated water because of mixing of precipitation and irrigation water and fractionation during evaporation from water surfaces. The ratio of strontium isotopes ($^{87}Sr/^{86}Sr$, hereafter Sr ratio) can be used to complement the shortcomings of the stable isotopes of water because it has the following characteristics: (1) temporal changes in the Sr ratio can be ignored at less than geological time scales, and (2) the effects of fractionation are negligible. In other words, the Sr ratio of water will change only because of interactions with the porous media it flows through (soil/rock), or mixing with water that have different Sr ratios. Although the use of the strontium isotopes for studying hydrological processes is increasing, their applicability in irrigated watersheds has not yet been examined.

We carried out the study described here in a typical agricultural watershed located on the alluvial fan of the Kinu River, namely the Gogyo River. The aim was to examine the potential for using the Sr ratios by investigating the following: (1) the variation in Sr ratios between water sources (i.e., precipitation, irrigation water, shallow aquifer, and streamflow), and (2) the temporal variation in the Sr ratios in relation to irrigation periods. We sampled water sources in irrigated (June) and non-irrigated (October) periods and analyzed the Sr ratios and concentrations as follows: (1) 23 samples of streamflow along the Gogyo River at 500 m intervals, (2) 56 samples of shallow aquifers, (3) precipitation in June and October, and (4) irrigation water of the main irrigation channel in June.

The Sr ratios of the samples were plotted against 1/Sr concentration. The streamflow samples were plotted linearly on the diagram, and the Sr ratio and 1/Sr concentration decreased along the direction of flow, indicating that the streamflow was composed of two end-members. One potential end-members was the irrigation water, which plotted near the higher end of the streamflow plot. The other was the water from the shallow aquifer, which plotted near the lower end of the plot.

The Sr ratios of soil water within paddy fields decreased as sampling depth increased. This suggests that as irrigation water percolates into the shallow aquifer, its Sr ratio decreases as it mixes with the soil water; whereas when irrigation water drains from paddies via surface channels, the Sr ratio will be less likely to change. The continuous decline in the Sr ratio along the stream suggests a conceptual model of exfiltration of irrigated water from the shallow aquifers. The water samples in the Gogyo River during the non-irrigated period had lower in Sr ratios and higher in Sr concentrations, suggesting a relative increase in contributions of the water from the shallow aquifers.

The stable isotopes of water also supported the above conceptual model that the streamflow was composed of water originating from the surface drainage system and the shallow aquifers. For stream water samples of the Gogyo River, $\delta^{2}H$ was highly correlated with $\delta^{18}O$. The slope of the regression line was approximately 6.0, suggesting that the streamflow was characterized by water that had been

 

subjected to high levels of evaporation in the paddies.
Our study shows that the Sr ratio-1/Sr concentration diagram can be used to elucidate the mixing ratio of the water from the surface and subsurface flow paths. The temporal changes in the contributions of flow from each flow path over the duration of the irrigation period will shed new lights on the hydrological processes in irrigated watersheds.

Keywords: strontium isotopes, irrigated paddies, surface-groundwater interactions

 