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Mixing analysis of groundwater recharge sources for better watershed management

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Abstract This paper describes application of three-end member mixing model with isotopic tracers to analyse groundwater recharge sources in the Nasu Fan, Japan. Relative contribution of river water accounts for 50-60% at areas adjacent to interrupted rivers, and precipitation fallen onto the fan is dominant recharge source at the other areas. Contribution ratio of paddy-field water is 30% at most. Implication of such results for better watershed management is given.

Key words tracer, stable isotope, groundwater-surface water interaction, rice paddy field, alluvial fan, end-member mixing model

INTRODUCTION

In an alluvial fan, there exist intensive groundwater-surface water interactions. For instance, rivers are often interrupted at the apex and/or middle zones of the fun because much river-water infiltrates underground and percolates toward water table through highly permeable sand/gravel layer(s). Similarly, precipitation fell onto the ground and irrigated water in paddy fields also easily infiltrate and recharge groundwater. On the other hand, we can find revival of the interrupted river and many springs at the rim zone of the fun, due to effluent seepage of groundwater. Such surface waters provided by groundwater discharge have played a crucial role in maintaining human activities and natural ecosystems. Therefore, assessment and conservation of various sources of groundwater are important issues for better managing of watershed particularly in alluvial fan.

The present study aims to evaluate quantitatively the relative contributions from different sources, such as river water, precipitation and irrigated paddy-field water, by a mixing analysis using stable isotope tracers.

STUDY AREA AND METHODOLOGY

The study area is the Nasu Fan, central Japan (Fig .1), which is a compound fan formed by four rivers (i.e., the Naka, Kuma, Sabi and Houki rivers). The two (the Sabi and Kuma rivers) of the four are fully interrupted at the apex zone and revive at around the boundary between the middle and rim zones. Total area of the fan is approximately 400km, with elevation ranging from 100 to 600 m a.m.s.l. Land use type is dominated by pasture and forest in the apex zone, and rice paddy and vegetable field in the middle

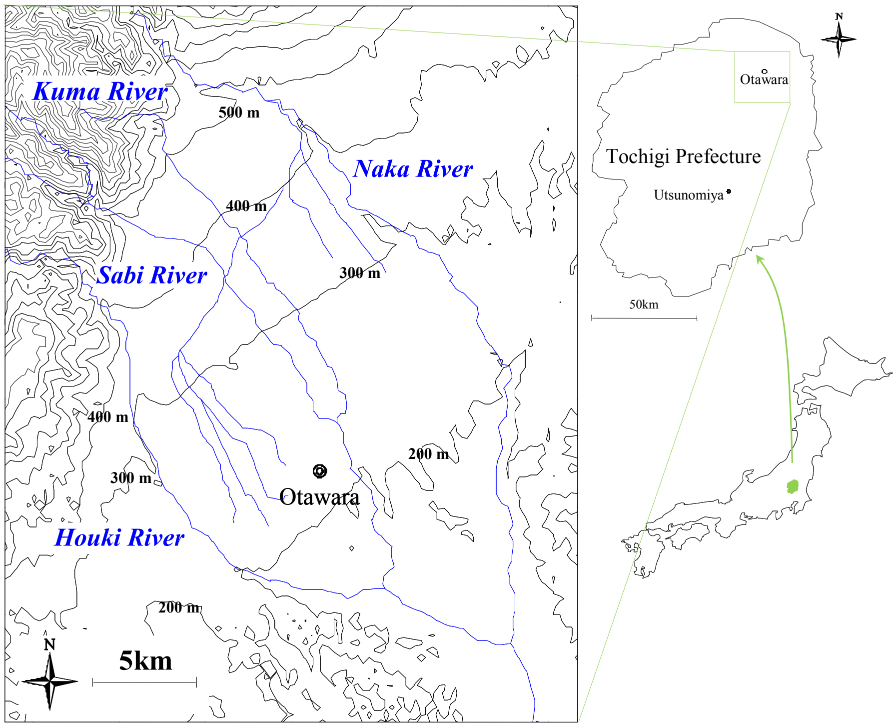

Fig. 1 Location and topography of the study area.

and rim zones.

Water table is situated within sand/gravel layers (called *Nasu Alluvial-fan Gravels* and *Torinome Gravels*) overlain by loamy soil layer with a thickness of approximately 2 m, and underlain by pyroclastic flow sediments (called *Otawara Pumice-flow*), which act as aquitard. The thickness of sand/gravel layers ranges from 20 to 30 m at the middle zone. Annual mean temperature is approximately 12 ºC, and annual precipitation is approximately 1350 mm.

The present study mainly focused on groundwater at the middle zone (with elevation ranging from 250 to 360 m), and ten wells were selected in the zone for groundwater sampling. The groundwater samples were collected every month during one full year from February 2004 to February 2005. In addition to groundwater, samples of river water (at four rivers), precipitation (at one site) and paddy-field water (at five sites) were also collected as potential recharge sources. All the collected samples were analyzed for hydrogen and oxygen stable isotopic compositions (δD and δ^{18}O) by a mass spectrometer (MAT252, Thermo Finnigan). Furthermore, groundwater level and water quality (including temperature, pH, electric conductivity and major ions concentration) were measured.

RESULTS AND DISCUSSION

Annual average δD and δ^{18}O in precipitation were -56.7‰ and -8.8‰, respectively. The values were lower in river water and higher in paddy-field water. The deuterium excess, *d* ($\equiv \delta D - 8\ \delta^{18}O$), was significantly lower in paddy-field water, indicating kinetic fractionation during evaporation from flooded water surface. In the δ-diagram groundwater isotopic data were plotted within a triangle of which end members are river water, precipitation and paddy-field water. This fact suggests that the groundwater is a mixture of these source waters.

Thus, a three end-member mixing model can be applied. This model is based on conservation of water, hydrogen isotope, and oxygen isotope. Relative contribution ratio, *R* (%), for each source can be obtained by solving simultaneously the three conservation equations, as:

$$R_p = \frac{(\delta D_g - \delta D_d)(\delta^{18}O_r - \delta^{18}O_d) - (\delta^{18}O_g - \delta^{18}O_d)(\delta D_r - \delta D_d)}{(\delta D_p - \delta D_d)(\delta^{18}O_r - \delta^{18}O_d) - (\delta^{18}O_p - \delta^{18}O_d)(\delta D_r - \delta D_d)},$$

$$R_r = \frac{(\delta D_g - \delta D_d)(\delta^{18}O_p - \delta^{18}O_d) - (\delta^{18}O_g - \delta^{18}O_d)(\delta D_p - \delta D_d)}{(\delta D_r - \delta D_d)(\delta^{18}O_p - \delta^{18}O_d) - (\delta^{18}O_r - \delta^{18}O_d)(\delta D_p - \delta D_d)},$$

$$R_d = 1 - R_p - R_r,$$

where subscripits p, r, d and g denote precipitation, river water, paddy-field water and groundwater, respectively.

Figure 2 shows spatial distribution of the computed *R* values. At an area adjacent to interrupted rivers (i.e., the Sabi and Kuma rivers), contribution ratio of river water is generally high. In contrast, at areas apart from rivers, river water shows no contribution and most of groundwater are recharged by precipitation onto the fan. While contribution of paddy-field water can be also found at all the region, the *R* is 30% at most. The results also indicate that the Houki River recharges groundwater, whereas the Naka River does not. The reason why there is no recharge from the Naka River is because river bed is situated far lower than water table within the fan. Validity of these findings from the mixing analysis is supported qualitatively by hydraulic data and the other data of water quality.

Knowledge of relative contribution of different groundwater sources allows us to discuss the effect of water use or land use on groundwater resources. In areas where river water contribution is dominant, construction of dams or river water pollution upstream will cause severe damage to quantity and quality of groundwater body. In areas where precipitation contribution is dominant, live stock farms and fertilization in pasture land or vegetable field may result in nitrogen contamination of groundwater. Construction of industrial waste landfills would also affect groundwater quality. In areas where paddy-field water contribution is dominant, abandonment of rice cultivation may decrease groundwater recharge and thus lower water table. In the last two areas, groundwater is particularly sensitive to land use change within the fan, so that regional planning including urbanization and agricultural land modifications should be carefully made.

CONCLUDING REMARKS

As shown in the present paper, mixing analysis of groundwater is capable of providing us invaluable information for decision making to manage better water and watershed.

Further studies under diverse geographical conditions are necessary to confirm reliability of the estimates from this approach.

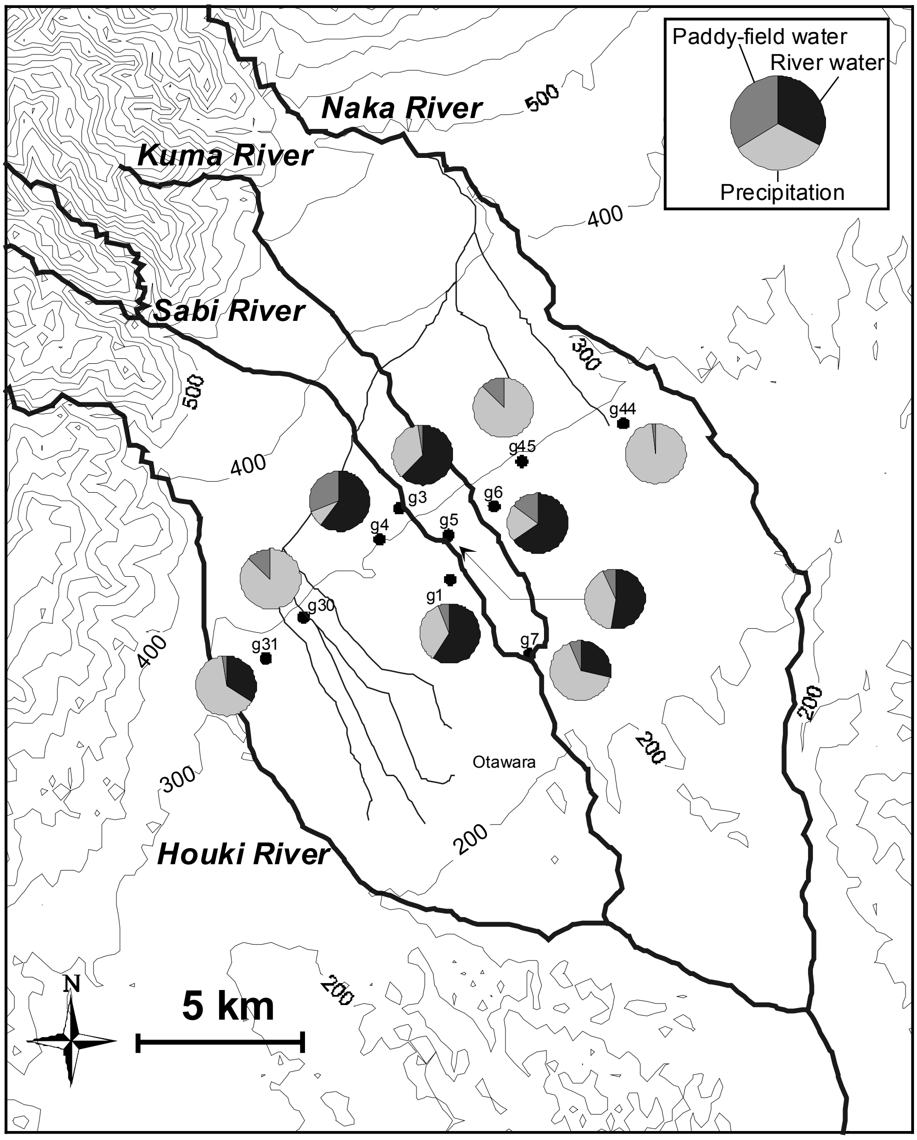

Fig. 2 Spatial distribution of contribution ratio for three possible sources.