Quantitative Analysis of the Paddy Irrigation Effects on Groundwater Recharge

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1. Introduction

Groundwater is a vital resource used for drinking, snowmelt management, and agricultural purposes. As a locally sourced water supply, groundwater recharge function through paddy fields has attracted attention in recent years. However, due to increasing urbanization, there is a significant reduction in paddy field area. This study aims to quantitatively evaluate the contribution of rice cultivation to groundwater recharge in a basin.

2. Study Area and Methods

The study area is in the Furukawa Kokufu Basin located in the Northern part of Gifu Prefecture. The surface water budget in the basin was quantified through surface water inflows measured at 9 locations (4 agricultural channels near the headwaters and 5 mountain streams) and the surface water outflows measured at 13 agricultural drainage channels (**Figure 1**).

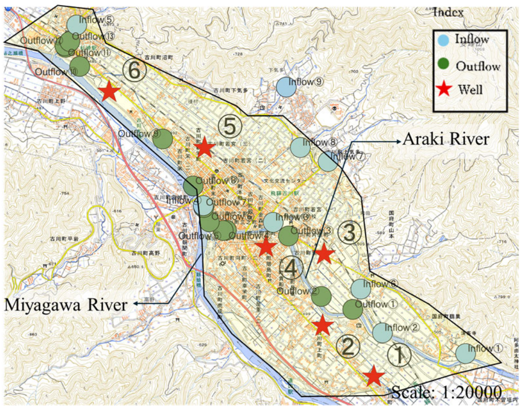

Figure 1 Schematic figure of study area and observation points

The observation period was from September 8, 2023, to November 25, 2024, excluding the winter months (Mid-December to March). The total area of the analysis domain is approximately 3.3 km^2 where, paddy field area is estimated as 1.3 km^2 (Fude Polygon, Ministry of Agriculture, Forestry and Fisheries) which is 39% of the total land area. Observation frequency was about twice a month with a total of 20 times within the period. Groundwater levels were continuously measured every 10 minutes at 6 wells by using Water Pressure Sensor (HOBO-U20-001-0, Onset). Potential evapotranspiration was calculated by using Penman Equation and the climate data were obtained from Takayama weather station of Japan Meteorological Agency (JMA).

3. Results and Discussions

3.1 Estimation of Groundwater Recharge Rate

If we assume that evapotranspiration rate from urban areas is ignorable, groundwater recharge rates within the basin during the period of no rainfall can be estimated by using the following water balance equation.

$$I_{deep} = Q_{in} - Q_{out} - ET \quad (1)$$

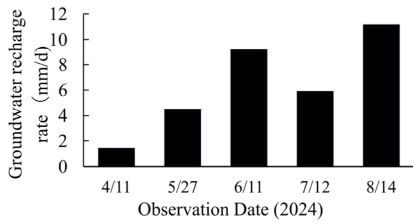

Figure 2 Groundwater recharge rate by water balance equation

Here, I_{deep}: groundwater recharge rate (mm/d), Q_{in}: surface inflow (mm/d), Q_{out}: surface outflow (mm/d), ET: potential evapotranspiration rate from paddy fields (mm/d). Amongst 20 observation data, 5 data within the irrigation season were found to be suitable for this calculation. As shown in **Figure 2**, during the irrigation period, ground water recharge rates increased with an average of 6.45mm/d ranging from 1.43 to 11.47 mm/d.

3.2 Groundwater level Trends

A typical case of groundwater level trends (10 days moving average) is shown in **Figure 3**. The results showed a significant increase in groundwater levels during the initial irrigation period (April 20–May 10, 2024), despite relatively a small precipitation (total 43 mm), indicating irrigation activities, particularly soil flooding and puddling role in groundwater recharge. A gradual decline followed during the tillering phase (late May to June), and some increase was observed during seedling formation. In contrast, during rice ripening (mid-August to September), when irrigation water was no longer supplied to the paddy fields, groundwater levels declined steadily across all monitored wells—even though the area received a total of 222.5 mm of precipitation.

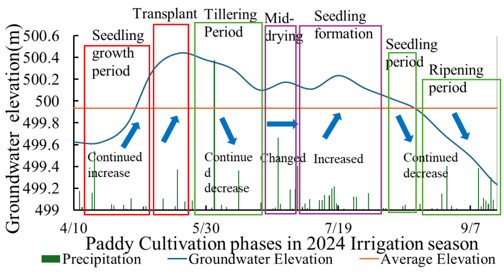

Figure 3 2024 Irrigation season groundwater level

3.3 Relationship between Paddy field Area and Groundwater level increase

Since initial irrigation period exhibited a significant rise in groundwater levels, we calculated groundwater level difference (groundwater change from April 20 to May 10) in each well. Groundwater level rose from 0.198m to as high as 0.81m and was higher in the upstream region than in the downstream region. Thus, as shown in **Figure 4**, we attempted to calculate the paddy cultivation area delineated within a 100m radius around each well, and plotted against groundwater level difference of each well. It was found that wells surrounded by larger paddy field areas had higher groundwater level difference and vice-versa.

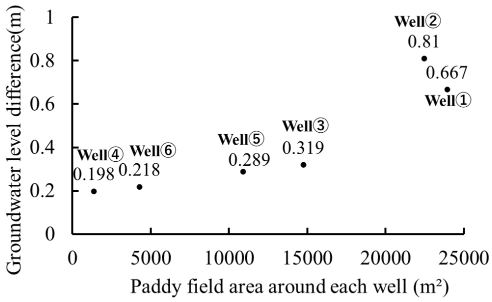

Figure 4 Groundwater level difference and paddy field area around each well

4. Conclusion

The findings helps to understand the behaviour of waterflow within the basin and highlights the role of paddy fields in groundwater recharge during the irrigation season. The analysis reveals a positive correlation between paddy field area and groundwater recharge, suggesting the significance of paddy cultivation in sustaining the groundwater recharge function. Currently, only the initial irrigation period has been evaluated, and the evaluation of other phases of irrigation is still lacking. Moreover, the effect of precipitation on groundwater recharge is not yet clarified.

As a future plan, we expect to develop a groundwater flow model by assigning the groundwater recharge rate obtained in this study as the boundary conditions and by calibrating the data with the measured groundwater level.

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