5.2 Water balance in the agricultural watershed of Kumamoto groundwater region

Kenji Tanaka*, Hirohisa Mizuno*, Daisuke Kuwamoto*, Hiroaki Taniguchi**, Takaomi Hokamura*, and Fumihiko Yamada*
*Department of Civil and Environmental Engineering, Kumamoto University, Kumamoto, Japan
** Kumamoto Prefectural Office, Kumamoto, Japan

1. Introduction

The Kumamoto Urban Region, which comprises the city of Kumamoto and its surrounding districts, is known as the largest urban groundwater region in Japan. Indeed, 100% of the water supply for nearly one million people in this region is dependent on groundwater. However, a decline in the amount of water in the region has occurred over the last few decades in response to a decrease in the recharge area (Kumamoto City Water Works, 2006; Tsuru et al., 2006).

The middle Shira River Basin is a key area for groundwater recharge. In this area, the geological structure of the surface layer has a high permeability. Additionally, a large groundwater path extends from this area to the Kumamoto Plain, in which there is a mean velocity of 40m/day (Kumamoto Prefecture and Kumamoto City, 2005). Field surveys have shown that the groundwater recharge area has a high capacity for recharge, with the soil infiltration rate ranging from 30 to 500 mm/day (Kiriyama and Ichikawa, 2004; Takemori and Ichikawa, 2007). Hence, it has been thought that the increase of seasonally flood area in the middle Shira River Basin is indispensable for preventing the decline of the groundwater level.

Although the needs of the water for groundwater recharge has been discussed in the previous studies, but the water balance between agricultural intake and river stream water had not been discussed. Tanaka et al. (2009) showed the outline of the annual cycle of the water balance between agricultural field and river streamwater based on field observation. They showed that the more than 40% of the stream water in the Shira River was taken into the agricultural fields for cropping and recharging water as a seasonal average during the summer. Much intake of the agricultural water diminished the stream flow of the main river severely especially in the pre-rainy season.

* Corresponding Author, Address: Kenji Tanaka, Department of Civil and Environmental Engineering, Faculty of Engineering, Kumamoto University, Kurokami 2-39-1, Kumamoto city, Kumamoto, 860-8555, Japan; email: ktanaka@st. kumamoto-u.ac.jp

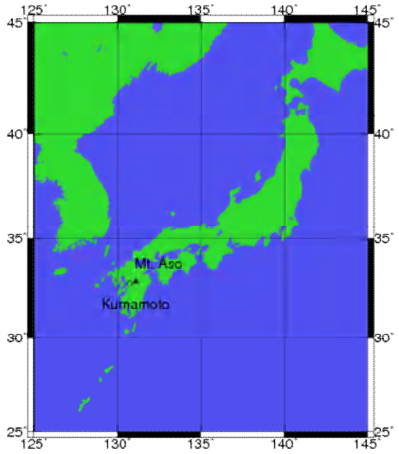

Figure 1 Location of Kumamoto in west Japan

A seasonal scale drought occurred from spring and summer of 2009. The total rainfall during 2009 spring season in the middle Kyushu Area (32-33N, 130-132E) was as lower than the half of that in normal year. During the summer in 2009, a long spell of no precipitation day was observed. In this study, the surface water budget during over the Shira River Basin is investigated to reveal the effect of the seasonal scale drought.

2. Study area in the middle Shira River Basin

Kumamoto is located in the middle of Kyushu Island, Japan (Figure 1). Shira River originates at Mt. Aso, and is running westward to Ariake Sea. The basin area is about 1,050 km^2, nearly 80% of which is shared by the

inner area of caldera of Mt. Aso. The middle and lower basin is very narrow: less than 5 km across the streamward direction as shown in the map of Figure 2.

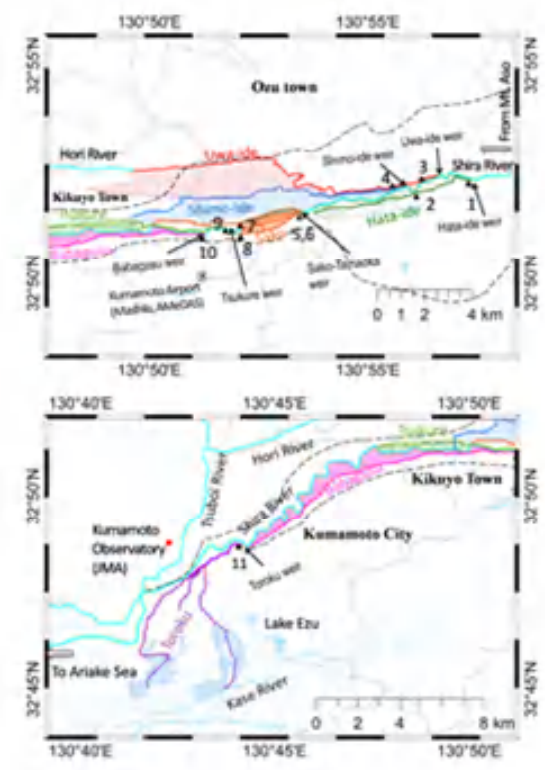

Figure 2. Study area in the Middle Shira River Basin, Kumamoto Japan. The dotted line shows the basin boundary. Numbers indicate the stations for measurement of the irrigation flow rate.

Table 1 List of station for measurement of irrigation water

No	Station Name	Latitude	Longitude	Alt (m)
1	Hata-ide 1	32°52′24.5″ N	130°57′10.8″ E	181
2	Hata-ide 2	32°52′04.0″ N	130°56′04.1″ E	164
3	Uwa-ide	32°52′17.4″ N	130°55′59.1″ E	145
4	Shimo-ide	32°52′12.5″ N	130°55′40.9″ E	143
5	Sako-1	32°51′37.3″ N	130°53′26.7″ E	95.5
6	Sako-2	32°51′37.7″ N	130°53′26,8″ E	95.5
7	Sako-3	32°51′16.7″ N	130°52′08.7″ E	83.5
8	Sako-4	32°51′07.8″ N	130°52′03.1″ E	88.2
9	Tsukure	32°51′18.0″ N	130°51′32.8″ E	77.2
10	Babagusu	32°51′07.7″ N	130°50′56.6″ E	65.7
11	Toroku	32°48′44.6″ N	130°44′06.8″ E	38.5

Figure 3 Flow rate measurement at Shimo-ide.

Seven intake weirs are in place for agricultural use. The hatched area shows the irrigation area of each agricultural waterway. Some agricultural water from the Shira River is returned to the Shira River, while some is directed to other river systems including the Horikawa River from Uwa-ide, and the Kase River from Toroku. In the Shira River, the Jinnai flow station operated by the MLIT (36.05 km from mouth of the river) is located immediately downstream of the Sako-Tamaoka Weir.

Eight stations (Hata-ide-1, Uwa-ide, Shomi-ide, Sako 1, Sako 2, Tsukure, Babagusu, and Toroku) are set for intake water, while three stations (Hata-ide 2, Sako 3, and Sako 4) are set for runoff into the Shira River. A pressure gauge (U20 HOBO) was installed to measure the water level at each of the 11 stations. In addition, a reference pressure gauge was installed at Babagusu Station to observe atmospheric pressure. An example of the landscape is shown in Figure 3.

3. Seasonal scale drought in the spring and summer 2009.

Figure 4 shows the monthly precipitation ratios in Japan from April to September in 2009, with the precipitation data provided by Japan Meteorological Agency (JMA). Throughout the period but in July, the precipitation over Kyushu Island was lower than the half of the normal year. High anomalies in July were mainly brought by severe squall systems accordingly with the Baiu front (e.g. Mizuno and Tanaka, 2010). However, the low precipitation anomalies can be found in the east and south Kyushu Island. In September, the precipitation was lower than half of the normal almost whole of Japan, and the precipitation lower than 25% of the normal can be found in the east Japan widely and in the middle Kyushu etc.

The ground rainfall record in Figure 5 showed that the monthly rainfall was lower than 100 mm in April, May, August and September in 2009, except in August at Aso

Otohime station, due to local scale severe squall on 10 Oct. 2009, with the 225.5 mm of total rainfall and 147 mm of 3 hourly rainfalls. Without this severe squall event, the variation of the monthly rainfall in Aso Otohime was similar to other stations in Shira River Basin.

A long spell of no precipitation day occurred from 16 August to 11 September in 2009 in Kumamoto Area. Figure 6 shows the spell length of no-precipitation day during the period of August and September 2009, obtained from rain gauge measurement by JMA, Kumamoto Prefecture, and Ministry of Land Infrastructure, Transport and Tourism (MLIT). Nearly one month of no-precipitation days were recorded (from 15 August to 12 September) mainly in lowland, coastal area. Light shower occurred over the mountainous area in late August and early September, however, the total rainfall was lower than 10 mm.

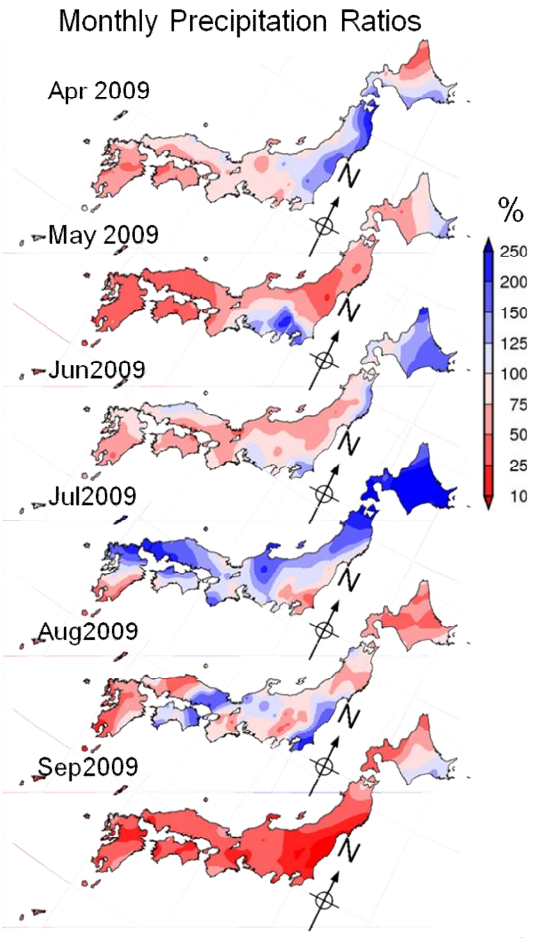

Figure 4 Monthly precipitation ratios obtained from rain gauge observation by JMA.

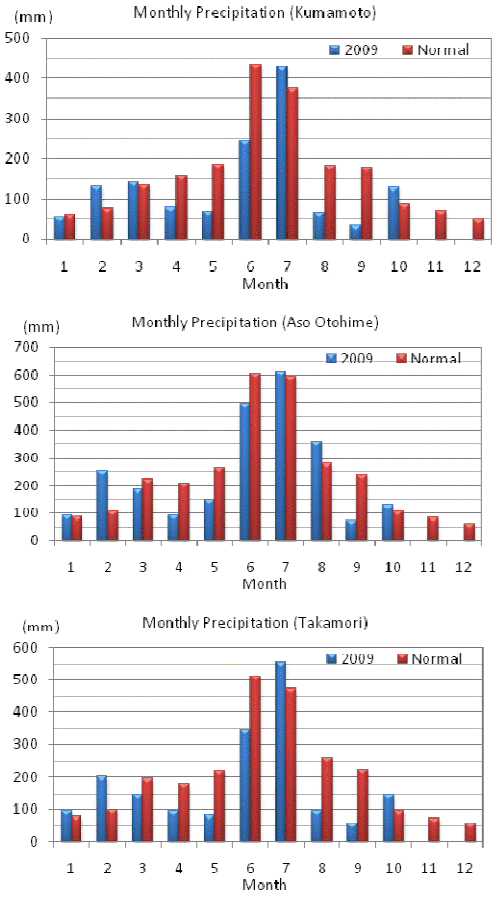

Figure 5 Monthly ground rainfall. Aso Otohime and Takamori are located inside the somma of Mt. Aso. Both of the sites are included Shira River Basin.

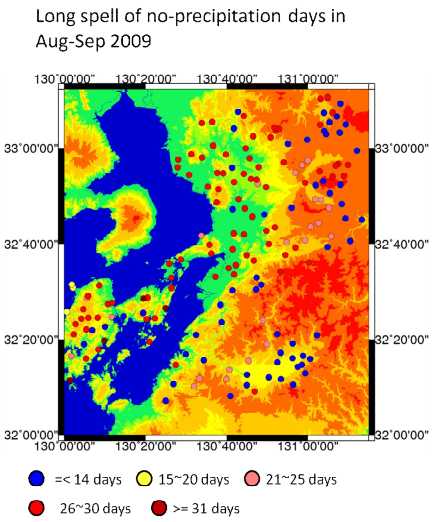

Figure 6 Spell length of no-precipitation days in Aug-Sep 2009

4. Water Balance in the Agricultural Area

The flow rate of irrigation channels taken from Shira River are plotted in Figure 7. The flow rate at Jinnal of Shira River is plotted in Figure 8, in which the colored line shows the record of 2009, and other lines indicates the statistical value calculated for each day-of-year.

The irrigation rate for each channels in 2009 was similar to that in 2008, although the precipitation was rather lower as compared to normal year. The flow rate increased corresponding to the transplantation period of the paddy rice in June, and the water channels were kept high water level till the harvest of paddy rice in the beginning of October. Depressions of the irrigation flow can be seen during the summer in response to heavy rainfall events.

The stream flow of Shira River in 2009 was much lower than the median of past 30-year record during the period from April to June and in September. Indeed, the 2009 stream flow sometimes exceeded to the median after heavy rainfall events of Baiu Season. Except such event, the plot of 2009 record is likely to follow lower 25% line of 30-year statistics. The flow rate at Jinnai in 2009 became lowest in the beginning of June, just before the onset of rainy season (i.e. Baiu) in that year.

Monthly water balance between irrigation channel flow and streamflow of Shira River is summarized in Table 2. The upper area represents the summation of the intake flow upstream from Jinnai flow station (i.e., Hata-ide 1, Uwa-ide, Shimo-ide, Sako-1,2), and lower area the intake downstream from Jinnai (i.e. Tsukure, Babagusu and Toroku), respectively. The total intake from Shira River in June and August was as high as the streamflow at Jinnai. It is found that the total irrigation became highest in September, in which the rainfall was extremely low as shown above. The total intake in September was about 2.5 times of the stream flow observed at Jinnai of the main river. It was because that there was not any rainfall event heavy enough to control the irrigation gate.

Figure 9 shows the water budget of Sako area, surrounded between irrigation channel and Shira River, with the numeric value denoted in millimeters. The water balance of such closed area can be written as

$$R = P - E + (Q_{in} - Q_{out}) \qquad (1),$$

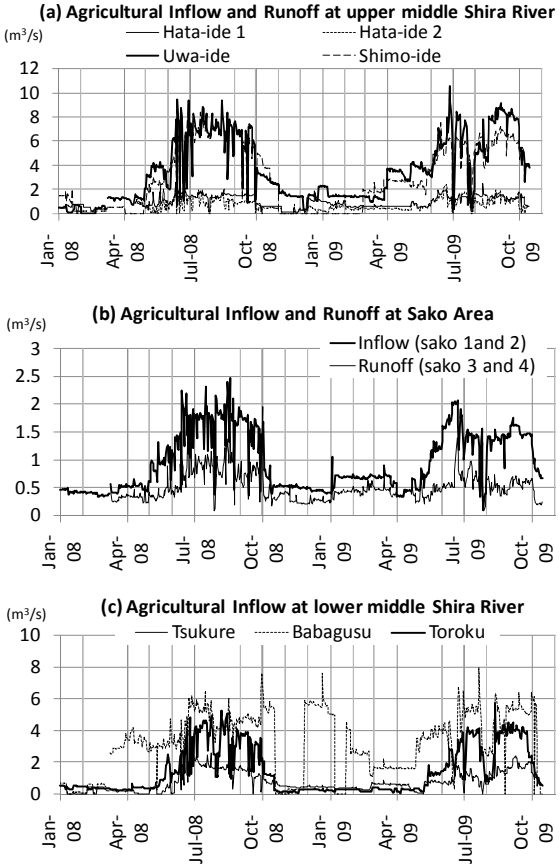

Figure 7 Flow rate of each irrigation channels taken from Shira River

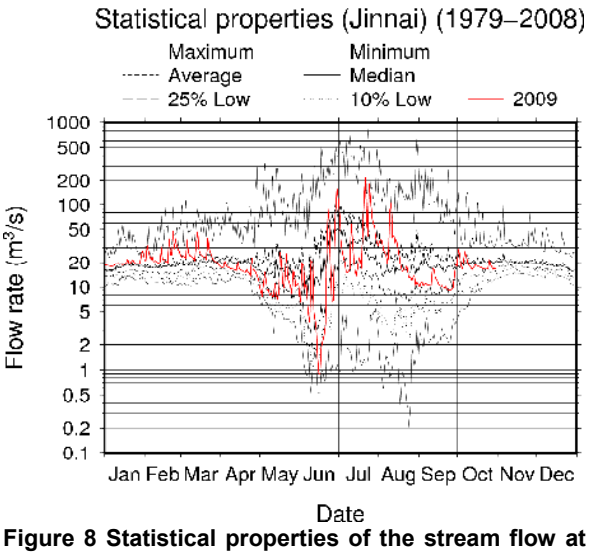

Figure 8 Statistical properties of the stream flow at Jinnai of Shira River. Colored line shows the observed record in 2009.

Table 2 Monthly average of irrigation flow rate and mean streamflow at Jinnai

Unit (m/s^3)

Month(2009)	Upstream	Downstream	Total	Jinnai
June	14.45	7.04	21.49	21.11
July	12.18	8.81	20.99	52.85
August	14.97	8.72	23.69	27.77
September	17.39	10.89	28.28	11.19

where R is a groundwater recharge from surface; P = precipitation to the targeted area; E = evapotranpiration from surface; Q_{in} and Q_{out} = agricultural irrigation and runoff, respectively. The observed precipitation data is used of AMeDAS Mashiki station (inside the Aso-Kumamoto airport), nearest weather station from the targeted area. Evaportranspiration was estimated from the surface energy budget scheme, using incoming shortwave radiation flux, air temperature, vapor pressure, and cloud cover ratio observed at Kumamoto Observatory Japan, considering the land use cover. The monthly net irrigation was ranged from 1300 to 2600 mm, more than five times higher than monthly precipitation. Most of the water recharged into underground was taken from Shira River.

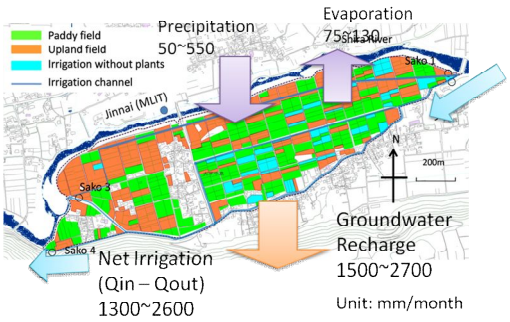

Figure 9 Landuse condition and monthly surface water budget at Sako Area

5. Conclusions

In the spring and summer season of the year 2009, the climate in the west Kyushu was basically rather dry, except in July the late Baiu season. Rainfall in the same season was as low as the half of the normal year. What is more, in September, a long spell of no-precipitation day, with the duration nearly one month, was recorded.

Although the total rainfall was much lower, the irrigation rate had not decreased. What is more, the total irrigation rate in September was the highest in the year of 2009. Because of no heavy rainfall event over the upstream of the basin in the same month, there was no need to control the gate of intake weir, as done in the late July in response to severe squall event in the late Baiu season. The limited water resource in seasonal scale drought made the water balance more and more difficult between for the agricultural use, including groundwater recharge for drinking water, and for the preservation of the river and coastal environment.

References

Kiriyama T., and Ichikawa, T., 2004: Preservation of ground water basin recharging by paddy field, Annual Journal of Hydraulic Engineering, Japan Society of Civil Engineers, 48, 373-378.

Mizuno, H. and Tanaka, K., 2010: Meso-β scale precipitation systems evolved at Tsushima Straits during late Baiu season in 2009, 22nd Conf. on Climate Variability and Change, 90th AMS Meeting, P1.21.

Takemori, Y. and Ichikawa, T. 2007: On Effect of Groundwater Evaluation by Keeping Water in no use Paddy field in the Middle Shira-River Area, Bulletin of School of Engineering, Kyushu Tokai University, Japan, 34, 1-8.

Tanaka, K., Funakoshi, Y., Hokamura, T., and F. Yamada, 2009: The role of Paddy Rice in recharging urban groundwater in the Shira River Basin, *Paddy and Water Environ. (revised)*

Tsuru, N., Akiyoshi, H., and Miyamoto, H. (2006) Groundwater pollution by nitrate-nitrogen in Kumamoto city, Annual Report of Kumamoto City Environmental Research Institute, 14, 59-67