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ScienceDirect
Procedia Environmental Sciences 28 (2015) 271 – 279
Procedia Environmental Sciences

The 5th Sustainable Future for Human Security (SustaiN 2014)

Irrigation practice and its effects on water storage and groundwater fluctuation in the first dry season in the rice cultivation region, South Sulawesi, Indonesia

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Abstract

Irrigation in *Renggang* Water Users' Association region in the first dry season, 2012 and 2013 was characterized by the reused water irrigation of drainage and the groundwater irrigation from wells. The shortage of the canal irrigation in 2012 was improved mainly by the renovation of the secondary canal by farmers' "*gotong royong*". The fluctuation of groundwater level was highly corresponded by the timely change of stored water in the ground (ΔS).The positive ΔS caused by the gross water supply in the first half period of the rice cultivation, was evaluated to keep the groundwater at some level.

Peer-review under responsibility of Sustain Society

*Keywords:*irrigation;dry season; rice cultivation;groundwater;reused water;water balance;Water Users' Association

1. Introduction

Rice is the most important grains in Indonesia since this crop is the staple food for majority of the people. To increase the production, rice is also cultivated in dry season. However, according to Bulsink et al.[1] and Ali[2] that it has been already known the amount of water resources in Indonesia fluctuates by season and is distributed unfairly between region to region. Suprapto[3] stated that in general, Indonesia has annual rainfall of 2700 mm in average. It is

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Peer-review under responsibility of Sustain Society
doi:10.1016/j.proenv.2015.07.035

said that only 278 mm of annual rainfall infiltrates and percolates into the ground to store groundwater and the larger portion of annual rainfall flows as direct runoff.

South Sulawesi is the third largest province of food production in Indonesia. Approximately 50% of total rice production in South Sulawesi owes to irrigation system. Considering the conflict between importance of rice and the limited water resources, Government of Indonesia launched the project of *Bili-Bili* irrigation system development in The *Je'ne Berang* River basin in Gowa regency, South Sulawesi to boost rice production. The irrigation system based on *Bili-Bili* dam has been developed since 1999. The minimum discharge of *Bili-Bili* dam occurs in the second dry season; from September until November and the highest discharge occurs from February until May due to the rainy season from December until April. Interestingly, the first dry season, which has more rainfall than in the second dry season, is from May until August.

Renggang Water Users' Association (WUA) region is in one of the lowest reaches of *Kampili* irrigation system, which diverts water from the *Je'ne Berang* River by Kampili weir. In this WUA region, irrigation water through the canal system has been insufficient even in the first dry season because of uncontrolled water distribution from *Limbung* primary canal damages in *Pammase* secondary canal. Therefore, this region reuses drained water from the adjacent region and pumps groundwater for irrigation for complementing the insufficient canal water. The reuse of drainage was originally designed in the series of the irrigation system development.

Groundwater is an important resource for water supply security in such a region of lowest reach in the irrigation system. One of advantages of the groundwater utilization from a well is that farmers can decide the time and quantity of pumping irrigation privately depending on the situation. On the other hand, the groundwater utilization should be controlled so that the ground water level would not decrease excessively by ground water uptake.

This study investigated the irrigation practice including the groundwater irrigation in *Renggang* WUA region in the first dry season and evaluated effects of irrigation on the water storage in the ground and groundwater fluctuations by applying water balance concept.

2. Material and Method

2.1. Study Site

This research was conducted in *Renggang* WUA region during the first dry season (Mayto August)in 2012and 2013. This WUA is under *Sirannuang* WUA Federation, which consists of seven WUAs. Administratively, this region is located in *Tanabangka* and *Gentungan* villages, West *Bajeng* district, Gowa, South Sulawesi Province, *Indonesia*. It is located at 5°19'4.08 – 5°19'52.32"Latitude and 119°24'7.2"–119°25'4.8"Longitude. *Renggang* WUA region is one of the last downstream areas of *Kampili* Irrigation System where irrigation water is supplied from *Pammase* secondary canal (*Pammase* S.C)diverted from the last gate of *Limbung* primary canal (*Limbung* P.C). Layout of the study area is shown in Fig. 1. for measurements of meteorology and evapotranspiration, experimental rice plot was installed.

2.2. Land use and rice cultivation in the first dry season in 2012 and 2013

Agricultural area of *Renggang* WUA was 74.12 ha in 2012 and 74.42 ha in 2013. As shown in Table 1, most of the area was cultivated by rice (94.50 % in 2012 and 94.63 % in 2013) in the first dry season.

Rice (*Oryza sativa* L.subsp. *Javanica*), cv. Ciliwung in 2012 and cv. Philipine in 2013was transplanted in the experimental plot on May 25 2012 and from May 23 until 24 2013. It was then harvested on Aug 25,2012 and Aug 20, 2013.

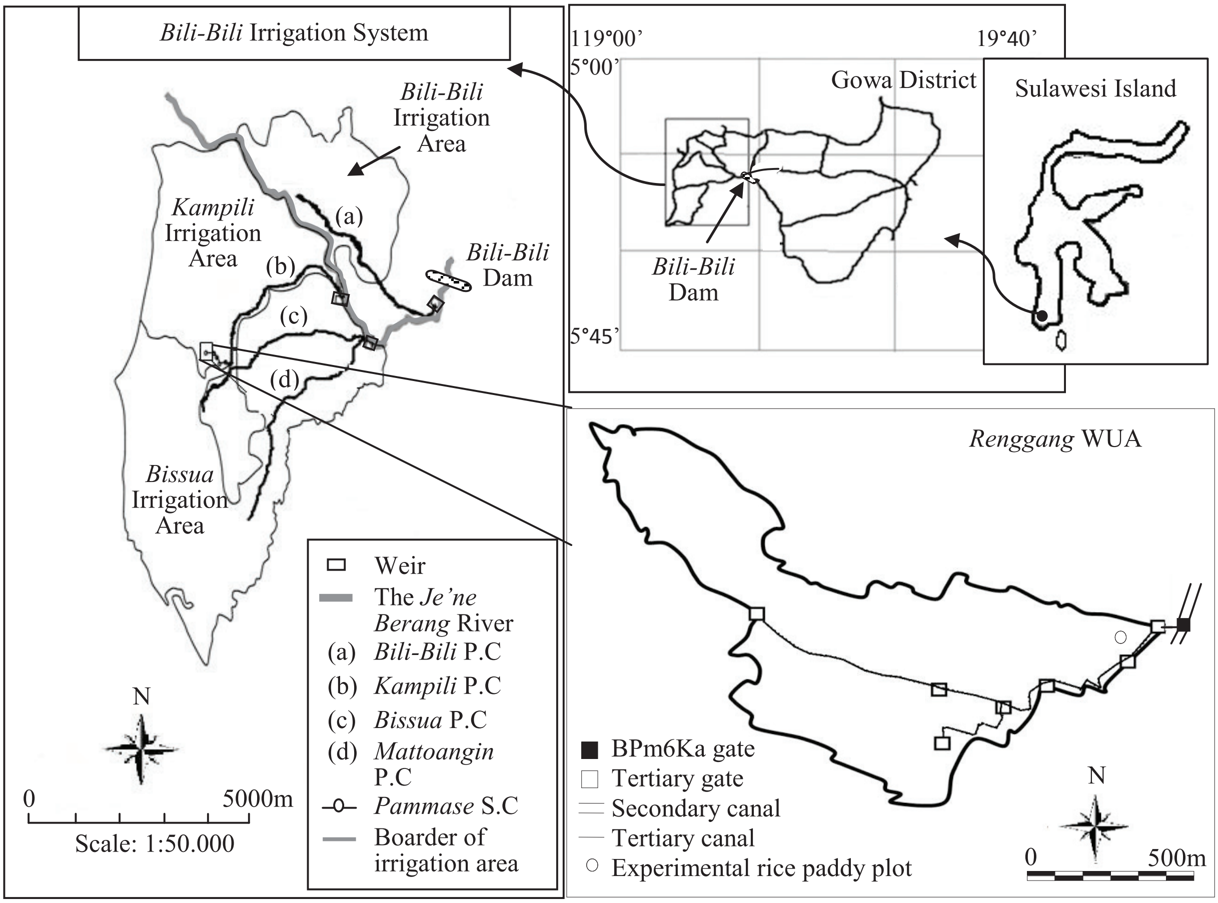

Fig. 1. Layout of the study area in *Renggang* WUA region, Gowa, South Sulawesi, Indonesia.

Table 1. Land use in *Renggang* WUA region in the first dry season.

Crops	Area (ha)		Area (%)	
	2012	2013	2012	2013
Rice	70.04	70.48	94.50	94.63
Green bean	0.76	1.26	1.03	1.69
Vegetable	0.30	0.75	0.40	1.01
Maize	0.48	0.20	0.65	0.27
No crops	2.54	1.79	3.43	2.40
Sum	74.12	74.48	100.00	100.00

2.3. Measurements

2.3.1. Climatic conditions

Rainfall (by ECRN-100, Decagon) and air temperature (by HMP155, Vaisala) were measured in the experimental rice paddy plot in *Renggang* WUA region. The data were sampled every 10 seconds and averaged every 10 minutes by using CR23X data logger (Campbell), while rainfall data was collected by Em5b data logger (Decagon).

2.3.2. Discharge of water supply measurement

Discharges of irrigation from *Pammase* secondary canal and the reused water irrigation from drainage of *Sappaya* WUA region, which was adjacent to *Renggang* WUA region, were estimated by measuring the velocities of water flow in each canal by a current meter (V-20, Kennex). Discharge of groundwater irrigation from wells by pumping was measured a couple of times manually by catching pumped water by a 10 *l* bucket in a measured time period and measuring the volume by a mess cylinder.

2.3.3. Plant height and LAI

Plant height was measured by averaging it, which often randomly selected every seven days during the rice growing period. The leaf area index (LAI) was estimated by measuring the size of ten leaves, calculating the average area of a single leaf by applying a relationship between the size and area of a leaf, which had been obtained for each rice cultivar, and multiplying by number of leaves of one rice plant.

2.3.4. Evapotranspiration

Evapotranspiration was measured by a lysimeter which consists of a container made of acryl, filled with soil, water and rice plants in the same planting density as the field. The surface area of lysimeter was5812.92 cm^2 (= 80.4 cm x 72.3 cm), the depth of soil in lysimeter was 20 cm and water depth was set to around 5.0 cm after every water level measurement. Daily and daytime evapotranspiration was obtained by the change of the water level in the lysimeter, which was measured by a water level gauge (PH-340, Kenek). The water level was measured at 8:30 and 17:30 LST every day.

2.3.5. Groundwater level

There are more than 100 wells on ridges of plots, which were dug by farmers, in *Renggang* WUA region. Groundwater was manually measured each day at nine fixed wells from upper to lower reach in this region.

2.4. Data Analysis

2.4.1. Water balance method

To estimate water storage in the ground, water balance method was applied. Considering hydrological processes in this region, where there is no surface drainage could be found in the concerned dry season, the water balance can be written as follows:

$$P + Qi + Qr + Gi = ET + \Delta S \quad (1)$$

where P is rainfall, Qi is the canal irrigation from *Pammase* secondary canal, Qr is the reused water irrigation from the drainage of *Sappaya* WUA region, Gi is the groundwater irrigation from wells, ET is evapotranspiration and ΔS is timely change of stored water in the ground.

2.4.2. Statistical data analysis

The change of water supply in the first dry season was compared between 2012 and 2013. The fluctuation of the groundwater level was assessed by the non parametric method such as the Mann-Kendall test. Carter et al.[4] suggested that the main reason for using non parametric statistical tests was its relatively higher suitability for non parametric distributed data, which were frequently encountered in hydro meteorological time series.

3. Results and Discussion

3.1. *Climatic conditions and agronomical terms*

Rainfall and air temperature in the study area during the rice growing period in the first dry season (112 days in 2012 and 107 days in 2013) are shown in Fig. 2(a) and (b). There were slight differences in meteorological condition between 2012 and 2013. Total rainfall of 163.8 (mm) in this season in 2012 was smaller than that of 294.4 (mm) in 2013. Average air temperature of 25.9 (^{o}C) in this season in 2012 was lower than that of 26.4 (^{o}C) in 2013. Through the growing period, air temperature decreased within the days after transplanting (DAT).

The plant height reached maximum height on 60 – 75 DAT, as shown in Fig. 2(c). The maximum height 93.7 cm on 60 DAT (24 July) in 2012 was shorter than 110.2 cm on 75 DAT (7 August) in 2013, partly due to cooler temperature condition in 2012. The peak of LAI was 6.76 on 53 DAT (17 July) in 2012 and 7.93 on 33 DAT (26 June) in 2013, as shown in Fig. 2(d). In addition, Sharfi and Hashem[5] state that the excessive nitrogen fertilizing in the early stage could caused the earlier peak of LAI in 2013.

3.2. Characteristic of irrigation practice

Statistically, monthly accumulations of the gross water supply (P + Qi + Qr + Gi) and the canal irrigation (Qi) in *Renggang* WUA region during the rice growing period in the first dry season were significantly different ($P<0.05$) between 2012 and 2013.

As shownin Fig. 3, the gross water supply for rice cultivation was 582.93 mm in 2012 and 904.29 mm in 2013. The canal irrigation was 151.93 mm in 2012 and 434.06 mm in 2013. Larger gross water supply in 2013 was due to larger rainfall and canal irrigation from *Pammase* secondary canal. The extraordinary small canal irrigation in 2012 was due to the following reasons. The first and a simple reason was smaller rainfall that year. The second reason was topographical condition of *Renggang* WUA region in the lowest reach of *Kampili* Irrigation System. The third reason was problems of the secondary canal, in which after more than ten years since the irrigation system had been constructed, some parts of irrigation canals had been broken due to the exceeded durability. Because of serious damages of *Pammase* between BPm4 and BPm5, which were divergence gates upstream of *Renggang*'s BPm6, and disordered BPm6, irrigation from this canal was very insufficient especially in the land preparation and transplanting stage in 2012.

The shortage of the canal irrigation was partly improved by the following renovations and also thanks to larger rainfall occurred in 2013. The gate BPm6 was repaired in the second dry season in 2012 by Agency of Water Resources Management in Gowa Regency.

The government regulation #20 about irrigation in 2006specified that the management of irrigation systemofa secondary canal is under control of local government and that of tertiary canal is under control of WUA. However, for a better management of the irrigation system, the regulation also permits WUA to control and improve the function of secondary canal system.

Therefore, the serious damages in *Pammase* was renovated by farmers in *Renggang* WUA and other concerned WUAs, whose fields are irrigated from BPm4 and BPm5,after finishing the rainy season in 2013. This farmers' work is generally called as "*gotong royong*". Taylor et al.[6] suggested that *gotong royong* is the cooperation among people to attain a shared goal. Before this work, the leader of *Renggang* WUA discussed with leaders of the other WUAs under the coordination of Federation of WUA (FWUA) *Sirannuang*. In such cases, an intervention of FWUA is needed as FWUA consists of WUAs which get benefits from a secondary canal. In addition, *Sirannuang* FWUA consists of seven WUAs including *Renggang*.

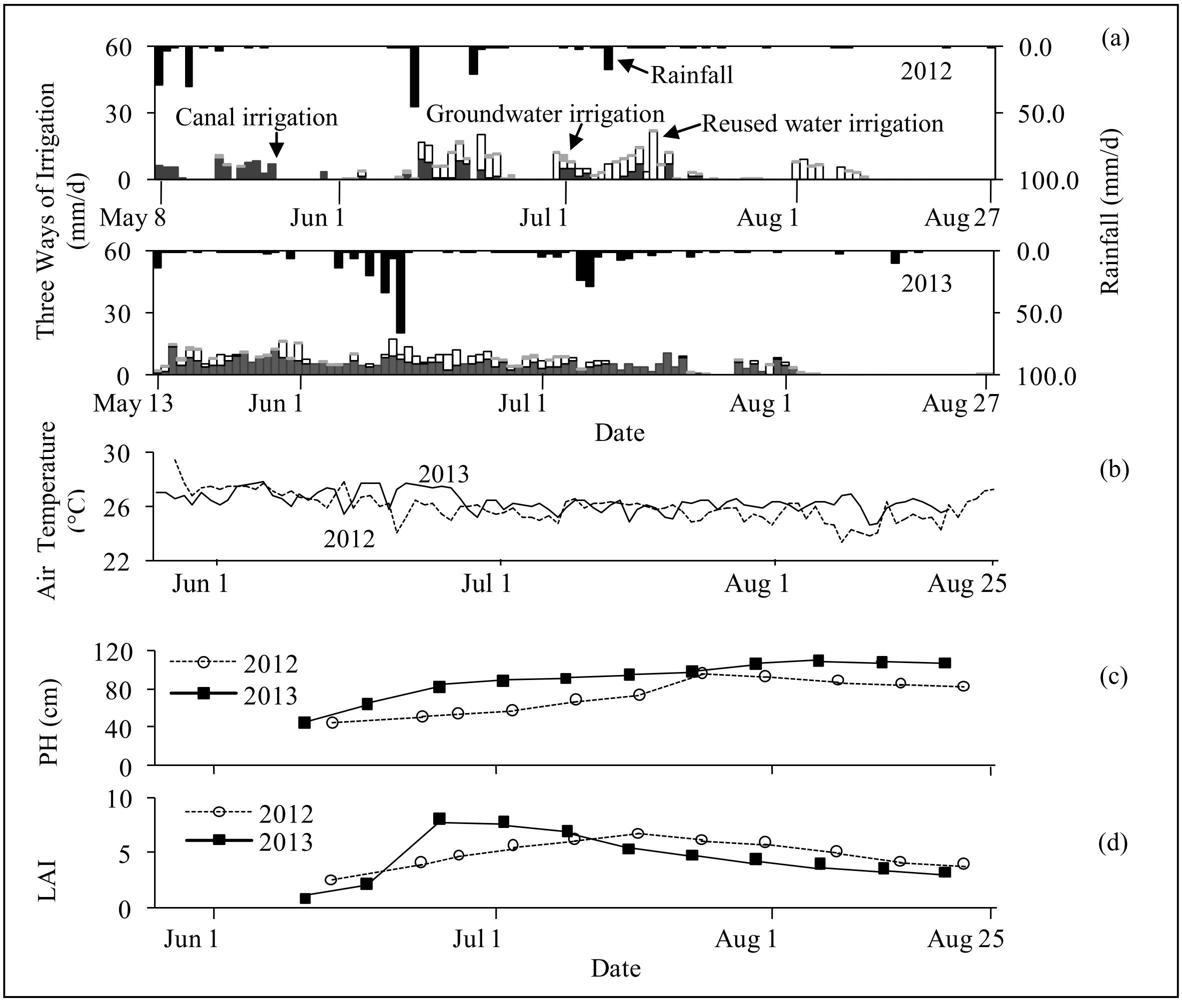

Fig.2. Daily climatic conditions and agronomical term of rice after transplanting to harvesting during first dry season 2012 and 2013 in Renggang WUA area. (a)gross water supply (: rainfall, : canal irrigation, : reused water irrigation, and : groundwater irrigation from the well), (b) air temperature at 2.0 m above the soil surface, (c)changes of plant height (PH) and (d) leaf area index (LAI) in 2012 and 2013. Rice (*Oryza sativa* L. subsp. *Javanica*) was transplanted on May 8 in 2012 and May 13 in 2013; harvesting dates were August 25 in 2012 and August 23 in 2013.

An increase of canal irrigation in 2013 expanded the field area that could be irrigated as shown in Fig. 4. The area irrigated by the *Pammase* secondary canal in the first dry season was 38.15 ha in 2012 and 48.98 ha in 2013. Hamdy[7] argues that the system of WUAs and WUA Federation can be evaluated to contribute to improve the irrigation system performance because of their advantages over a public agency to respond quickly to on-site problem.

Due to the increased amount of rainfall and the canal irrigation, the reused water irrigation of drainage from *Sappaya* WUA region decreased from236.17 mm in 2012 to 156.94 mm in 2013. Also, the groundwater irrigation from wells could decrease from31.03 mm in 2012 to 18.89 mm in 2013.However, both monthly reused water of drainage and monthly groundwater utilization were not significantly different in these two years.

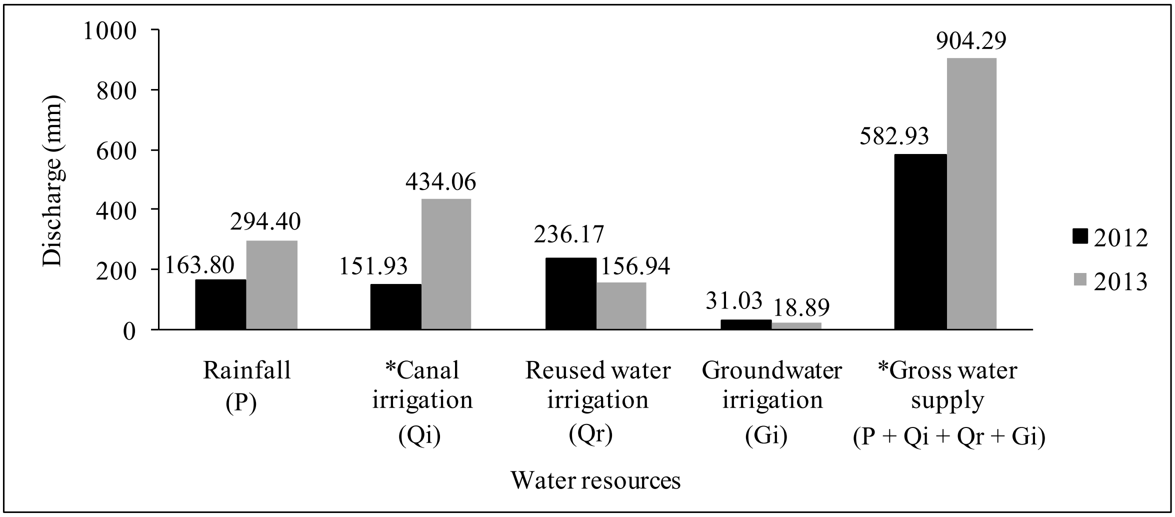

Fig.3. The changing of gross water supply from each water resources (rainfall, canal irrigation, reused water irrigation, and groundwater irrigation) for rice cultivation during first dry season in Renggang WUA area, 2012 and 2013 (* : significantly differ between two years, the level significant was set as α< 0.05).

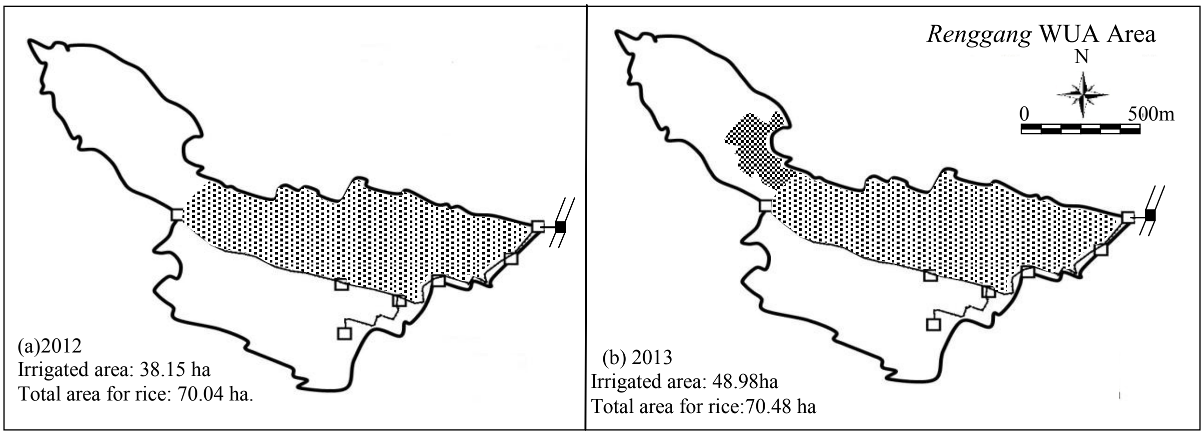

Fig. 4. Cultivation area for rice that could irrigated in the first dry season (a) 2012 and (b) 2013 in *Renggang* WUA agriculture area (░ : area that reached by irrigation water in 2012 and 2013, ▒ : additional area that reached by irrigation water in 2013; ■ : BPm6, : □ Tertiarygate; — : Tertiary canal).

3.3. The effect of irrigation on the water storage and groundwater fluctuation

Measured and analyzed results of water balance in *Renggang* WUA region in the first dry season 2012 and 2013 are shown in Table 2. The change of stored water in the ground (ΔS) was calculated by the water balance equation (1). It was revealed that the three ways of irrigation, which consisted of the canal irrigation (Qi), the reused water irrigation of drainage from another region (Qr) and the groundwater irrigation from wells (Gi), contributed 72 % to the gross water supply in 2012 and 67 % in 2013. Among the three ways of irrigation, Qr accounted largest part in 2012, while Qi did in 2013. It was revealed that an alternative way like reusing water of drainage could be functioned as an important water supply under some problems in the irrigation system in 2012.

The total ΔS through the rice growing period; 52.04 mm in 2012 was much smaller than 449.69 mm in 2013. The positive ΔS means that a part of gross water supply, which consists of rainfall and three ways of irrigation, was conserved in the ground. The negative ΔS, on the other hand, means that stored water in the ground was consumed for evapotranspiration, as the gross water supply could not meet evapotranspiration. In August in both years and even on July 2012, insufficient water supplies caused the stored water consumption for evapotranspiration, which resulted in the negative ΔS.

Table 2. Water balance in *Renggang* WUA region in the first dry season 2012 and 2013.

Month		P (mm)		Qi (mm)		Qr (mm)		Gi (mm)		P+Qi+Qr+Gi (mm)		ET (mm)		ΔS (mm)	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
May, 8 - 31, 2012 May, 13 - 31, 2013		66.0	29.0	68.9	138.0	0.0	46.5	2.4	8.1	137.3	221.7	0.0	20.1	137.3	201.6
June		71.0	154.0	47.2	166.2	95.2	76.1	13.9	5.8	227.2	402.1	179.5	118.6	47.7	283.5
July		25.4	97.6	35.8	118.8	95.3	33.1	13.0	2.3	169.6	251.9	176.7	155.8	-7.2	96.1
August, 1 - 27, 2012 and 2013		1.4	13.8	0.0	11.0	45.7	1.2	1.7	2.6	48.8	28.7	174.7	160.1	-125.9	-131.4
Sum	(112 days, 2012) (107 days, 2013)	163.8	294.4	151.9	434.1	236.2	156.9	31.03	18.9	582.9	904.3	530.9	454.6	52.0	449.7
Percentage (%)		28.1	32.6	26.1	48.0	44.5	17.4	5.8	2.1	100.0	100.0	91.1	50.3	8.9	49.7

The effect ofΔS on the groundwater level fluctuation during the first dry season was illustrated in Fig. 5. As a whole, the variation of ΔS corresponded to the variation of the gross water supply (P + Qi + Qr + Gi). The groundwater level rose or kept relatively constant situation in response to the positive ΔS and it dropped in response to the negative ΔS. The results of the Mann-Kendall test for the fluctuation of groundwater and ΔS, and for the gross water supply and ΔS were highly corresponded at the 99% level.

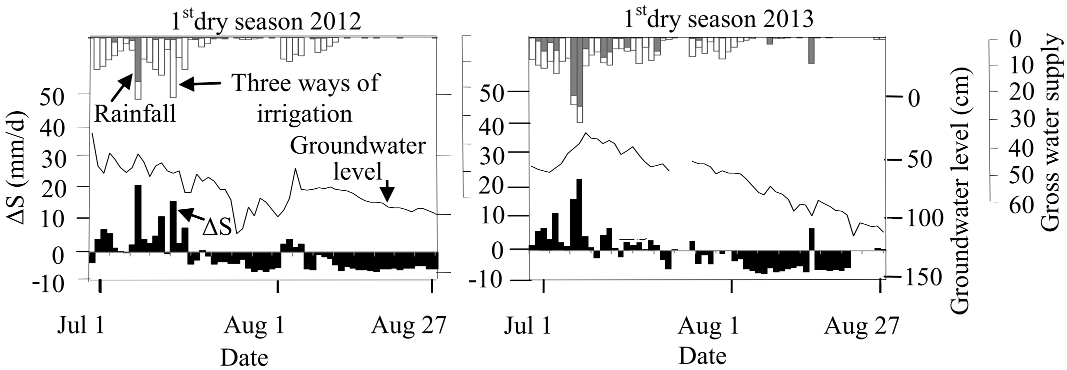

Fig. 5. Daily fluctuation of groundwater level during first dry season 2012 and 2013 in the rice field. (▬ : ΔS or timely changes of stored water in the ground, —— : groundwater level, ▬▭ : rainfall and 3 ways of irrigation as a gross water supply).

The positive ΔS, which was caused by the gross water supply; rainfall, the canal irrigation, the reused water irrigation and the groundwater irrigation in the first half period of the rice cultivation, can be evaluated to keep the groundwater at some level around 20 to 60 cm. From this reality, the conserved water in the ground could have made the groundwater irrigation possible in this period and also in the second half period of this season. Moreover, the conserved water in the ground was effectively utilized for consumptive water of rice under the shortage of the surface water especially in the last growing stage.

The conserved water in the ground in the first dry season would have also contributed to the agricultural production in the second dry season, when rainfall is smaller than in the first dry season. This will be investigated in another paper.

4. Conclusion

The aims of this study was to investigate characteristics of the irrigation practice, which included the groundwater irrigation, in *Renggang* Water Users' Association (WUA) region in the first dry season in 2012 and 2013 and to evaluate effects of irrigation on the water storage in the ground and groundwater fluctuations by applying water balance concept. This WUA region, which is in one of the lowest reaches of the irrigation system, reused drained water from the adjacent region and pumped groundwater for irrigation for complementing the insufficient canal water.

Firstly, characteristics of the irrigation practice could be summarized as follows. The water balance in this region in the first dry season in 2012 and 2013 showed that there were three ways of irrigation, which consisted of the canal irrigation (Qi), the reused water irrigation of drainage from the adjacent region (Qr) and the groundwater irrigation from wells (Gi), contributed 72 % to the gross water supply in 2012 and 67 % in 2013. Among the three ways of irrigation, Qr was the largest part in 2012, while Qi did in 2013. Further, there was an alternative way such as reusing water of drainage could be useful as an important water supply with some limitations in the irrigation system in 2012. The shortage of Qi in 2012 was improved mainly by two ways other than the larger rainfall (P) in 2013. The first way could be done was repairing the gate of the secondary canal by the local government. The second one was repairing serious damages in the secondary canal by farmers' "*gotong royong*" in *Renggang* WUA and other concerned WUAs under the coordination of Federation of WUA (FWUA)at the end of rainy season in 2013. Thus, there was an increase Qi in 2013, which expanded the irrigated field area. The system of WUA and FWUA could be further evaluated of how to improve the irrigation system performance.

Secondly, effects of irrigation on the water storage in the ground and groundwater fluctuations were revealed by applying the water balance concept as follows. The total timely change of stored water in the ground (ΔS) throughout the first dry season was 52.04 mm in 2012, which was much smaller than 449.69 mm in 2013 due to the smaller gross water supply (P + Qi + Qr + Gi) in 2012. In August in both years and even in July 2012, however, inadequate water supplies caused the stored water consumption for evapotranspiration, which resulted in the negative ΔS. The variation of ΔS during the season corresponded to the variation of the gross water supply. The groundwater level rose or kept relatively constant situation in response to the positive ΔS and it dropped in response to the negative ΔS. The positive ΔS, caused by the gross water supply in the first half period of the rice cultivation, could be evaluated to maintain the groundwater at some level around 20 to 60 cm. From this reality, the preserved water in the ground was evaluated to make the groundwater irrigation possible in this period and also in the second half period of this season. Moreover, the conserved water in the ground was effectively utilized for consumptive water of rice under the shortage of the surface water especially in the last growing stage.

Acknowledgement

This research was partially supported by the Circulation Program-09-Init, "Designing Local Frameworks for Integrated Water Resources Management" under "Water Management Project", Research Institute for Humanity and Nature (RIHN), Japan.

References

1. Bulsink, F., A.Y. Hoekstra, M.J. Booij. The water footprint of Indonesian provinces related to the consumption of crop products. *Hydrology and Earth System Science* 2010;14:119–128.
2. Ali F. Mohamad. Challenges of integrated water resources management in Indonesia. *Water* 2014;6:2001–2020.
3. Suprapto Ato. Land and water resources development in Indonesia. *Proceedings of The Regional Consultation,* FAO 2002. p. 233–242.
4. Carter, R. W. and Davidian, J. General procedures for gaging streams, U.S. Geol. Surv. Techniques of Water Resources Investigation, Book 3, Chapter A-6; 1968.
5. Sharfi. P, and Hashem, A. Evaluation eighteen rice genotypes in cold tolerance at germination stage. *World Applied Science Journal* 2010; 11(11):1476 – 1480.
6. Taylor, Paul Michael, Aragon, Lorraine V. Beyond the Java sea: Art of Indonesia's outer island. Abrams. 1991. p. 10.
7. Hamdy Atef, Cosimo Lacirignola. *Water users' association and sustainability of irrigation system*. Medit 1997, No. 3. p. 5.
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