Environmental Earth Sciences (2020) 79:142
https://doi.org/10.1007/s12665-020-8868-x

THEMATIC ISSUE

Earthquake effects on artificial groundwater recharge efforts in south Japan

Tsutomu Ichikawa[1] · **Kei Nakagawa**[2] · **Ronny Berndtsson**[3]

Received: 29 December 2018 / Accepted: 18 February 2020 / Published online: 9 March 2020

Abstract
The Kumamoto area includes 11 municipalities and a population of about one million. The area represents the largest total use of groundwater in Japan. The main recharging area for this groundwater used to be paddy fields for rice production located along the mid-stream section of the Shirakawa River. In the past few decades, the area of paddy fields has rapidly decreased due to the Japanese government's rice production adjustment policy and urbanization. In consequence, the groundwater recharge decreased from 656.2 million m^3 in 1992 to 606.9 million m^3 in 2006. Thus, groundwater recharge from paddy fields only might not be sufficient for groundwater demand in the future. For this reason, an artificial recharge system was established to increase groundwater recharge. In this study, we review the history of groundwater management and results of 14 years' operation of a large-scale artificial groundwater recharge project in the Kumamoto area. We visualize the resilience of the groundwater management and recharge project by influence of the 2016 Kumamoto Earthquake. It is shown that through an integrated approach of all societal groundwater stakeholders, a sustainable groundwater management can be achieved. The hydrological methods in this integrated approach quantify recharging groundwater volumes for different types of recharge fields by use of 170 local experimental observations. Results and experiences outlined in this paper can be used by planners and managers of dwindling groundwater resources to build resilient systems for groundwater recharge by involving all societal stakeholders through an integrated approach.

Keywords Kumamoto earthquake · Artificial recharge system · Paddy field infiltration · Resilient groundwater management

Introduction

To meet future increasing demand of water resources, groundwater recharge is an important component of the hydrological balance. Generally, groundwater recharge is a natural part of the hydrological cycle. However, increasing groundwater use and decrease of natural recharge often lead to decreasing groundwater levels (Alley 2009). For this reason, improved artificial recharge systems are necessary. The type and method of artificial recharge have to be adapted to the local hydrological and geological conditions (e.g., Todd 1959; Signor et al. 1970; Pyne 1995; U.S. Geological Survey 2002). In the 1950s, artificial recharge in Japan was dominated by well injection methods. In the 1980s, flooding-type methods using irrigation channels and paddy fields during non-farming periods and infiltration ponds became widely used. Hida (2002) describes in detail the historical background and research on artificial recharge of groundwater in Japan. In recent years, however, recharge on flooded paddy fields has decreased due to decreasing area for rice production in Japan.

Kumamoto with an area of 1041 km^2 is constituted by 11 municipalities centered around Kumamoto City. The area contains a population of about one million people with the largest total groundwater use in Japan. The main

This article is a part of the Topical Collection in Environmental Earth Sciences on "Groundwater Resources and Sustainability" guest edited by Nam C. Woo, Xiaosi Su, Kangjoo Kim and Yu-Chul Park.

✉ Kei Nakagawa
kei-naka@nagasaki-u.ac.jp

[1] Department of Kyushu Liberal Arts Education, Tokai University, 9-1-1 Toroku, Higashi-ku, Kumamoto 862-8652, Japan

[2] Institute of Integrated Science and Technology, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan

[3] Division of Water Resources Engineering, Center for Middle Eastern Studies, Lund University, Box 118, 221 00 Lund, Sweden

recharging area for groundwater in the Kumamoto area used to be rice paddy fields that were located along the midstream section of the Shirakawa River flowing from the mount Aso Caldera through the Kumamoto City to the Ariake Sea in an east-westerly direction (Fig. 1). The first managed paddy field constructions in this area were organized in the beginning of the Edo period (1589–1614) by Kiyomasa Kato who ruled over the Higo Province (present Kumamoto Prefecture) (Kumamoto Groundwater Workshop and Kumamoto Development Research Center 2000). He organized construction of seven weirs along the midstream section of the Shirakawa River to divert water to local rice farming (Kumamoto Groundwater Workshop and Kumamoto Development Research Center 2000). During the Meiji period (1868–1912), the region had developed into the largest rice production area of the prefecture with about 1500 ha of paddy fields. The area has a general high seepage capacity of above 100 mm/day (Kiriyama and Ichikawa 2004). As a result, groundwater levels in the Kumamoto area and discharge from the downstream spring water areas in the midstream section of the Shirakawa River increased substantially (Kumamoto Groundwater Workshop and Kumamoto Development Research Center 2000). Cross-sectional geological profiles of the Kumamoto groundwater basin have been surveyed along 1-km intervals as indicated in Fig. 2 (Kumamoto Foundation Society 2010). Figures 1 and 2 show the general flow situation of groundwater from the mid-stream Shirakawa River Basin to the down-stream Ezuko Lake.

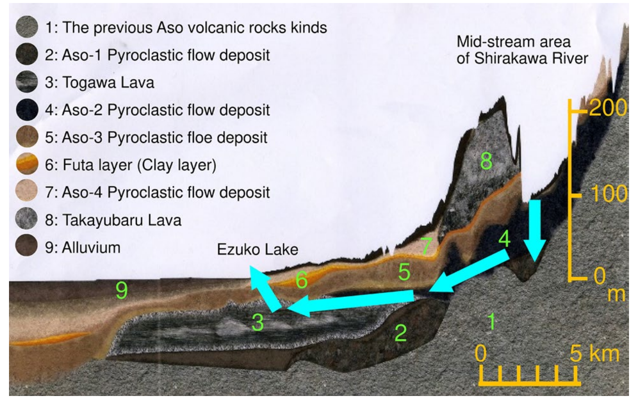


Fig. 2 Example of cross-sectional geological profile and general groundwater flow

It has been estimated that the annual groundwater recharge volume from the midstream section of the Shirakawa River rice paddy fields constituted about 10–20% of the total groundwater recharge volume in the Kumamoto region (Kiriyama and Ichikawa 2004). Thus, these paddy fields represented an important regional groundwater recharge area. However, as a result of changes in consumer preferences in the 1970s, demand for rice in Japan dropped significantly, and a rice surplus situation occurred. For this reason, the Japanese government launched a rice production adjustment policy (economic subsidies to farmers who converted from rice to other crops to curb rice production). As a result, the cropping of paddy rice in Ozu-cho

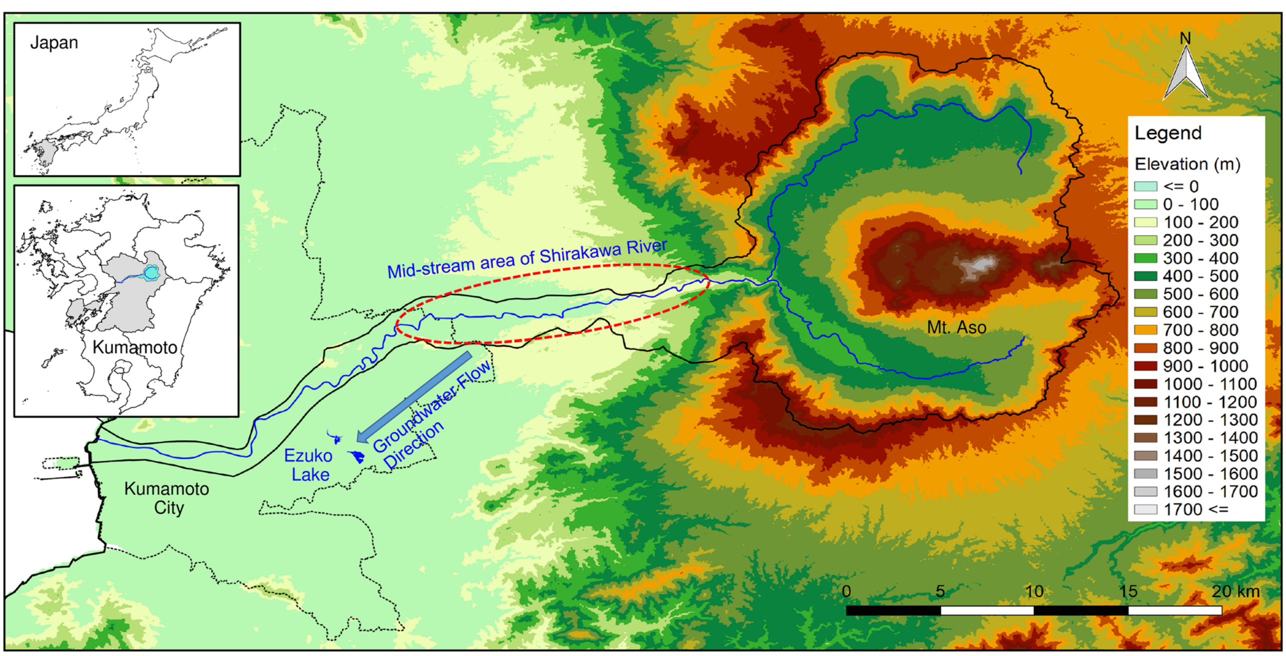


Fig. 1 Location of the experimental study area in Japan

and Kikuyou-cho, Kikuchi-gun, Kumamoto Prefecture in the midstream of Shirakawa River Basin decreased by 20% in 1979, 32% in 1990, and 40% in 2000. There was also a decline in agricultural land due to urban development after the rapid economic growth of the 1970s. By 1998, the planted acreage rate of paddy fields had fallen to 56.8% of the original paddy field area (Kiriyama and Ichikawa 2004). Thus, groundwater recharge amount decreased with the reduction of paddy field area, and total recharge amount of Kumamoto area was estimated at approximately 656.2 million m^3 in 1992 compared to approximately 606.9 million m^3 in 2006 (Kumamoto Prefecture 2008a). Therefore, it was recognized that the groundwater recharge by paddy fields alone might be insufficient if the groundwater supply demand in the future should be satisfied (Kumamoto Groundwater Workshop and Kumamoto Development Research Center 2000).

In view of the above, a project to increase the groundwater recharge started in 2004 as a cooperation between Kumamoto City, five private groundwater using companies, and local farmers. The project continued for 12 years until 2016. Local participation involved farmers who were willing to flood their fields during the fallow period. The fallow flooded fields would thus act as artifical groundwater infiltration areas. In turn, the project would allow for recovering of the water balance and preserving groundwater for future use.

In 2016, however, the Kumamoto earthquake occurred on April 14 and 16 before rice planting. The first seismic shockwave of the hypocenter (foreshock) was Mj 6.5 at a depth of 11 km, and the second (mainshock) Mj 7.3 at a depth of 12 km. The Kumamoto earthquake caused widespread destruction. The active Futagawa fault causing the earthquake belongs to the Hinagu fault group. The epicenter is shown in Fig. 3 and the earthquake characteristics are specified in Table 1. The earthquake caused an inland landslide and a settlement on the north side of the Futagawa fault moved 2 m in the east–west direction (Geographical Survey Institute, Japan). As a result, the areas of Mashiki-cho, Nishihara-mura, Aso City, and Minami-Aso-mura near the Futagawa fault were damaged. At the same time, channels supplying irrigation water to the paddy fields in the artifical recharge system were destroyed. Consequently, this caused great damage to the farming activities. In addition, torrential rainfall followed in June 2016, causing the slopes de-stabilized by the earthquake to collapse.

Thus, paddy fields in the middle part of the Shirakawa River basin were seriously affected by these disasters. Many of the irrigation channels supplying water to the paddy fields were sealed off and could not supply water for

Table 1 Characteristics of the earthquakes

	Foreshock	Mainshock
Origin time (UTC + 9)	21:26 April 14 2016 JST	01:25 April 16 2016 JST
Location	32.742° N 130.808° E	32.753° N 130.762° E
Depth	11 km	12 km
Magnitude	6.5 ml	7.3 ml

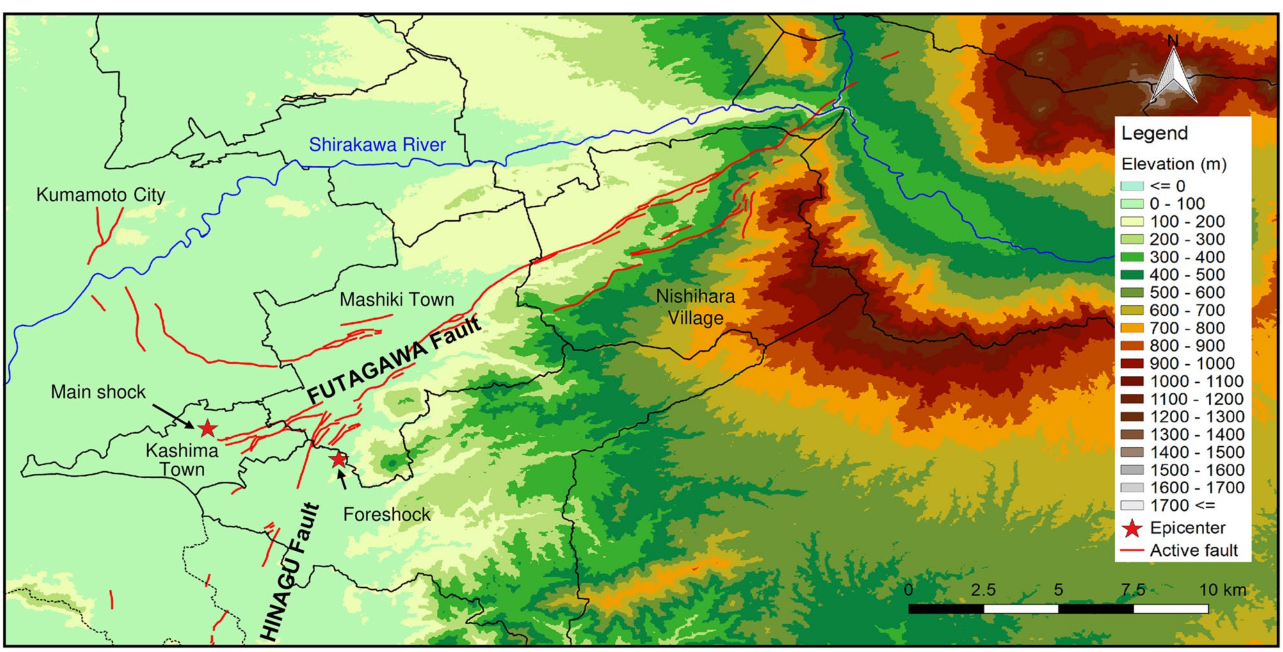


Fig. 3 Location of active fault and epicenter

artificial groundwater recharge. Research on relationships between earthquakes and water supply is mostly concerned with earthquake periodicity and methods to avoid damage (e.g., Goto et al. 2007; Kataoka et al. 2013; Yoshizawa et al. 2018). To the authors' knowledge, there is no corresponding research on long-term resilience of groundwater management and post-event assessment of the impact on artificial recharge and related hydrological analyses. In view of the above, the objectives of this study are firstly to review the history of groundwater management and results of the long-term operation of the large-scale artificial groundwater recharge project in the Kumamoto area. The resilience of groundwater management and artificial recharge by influence of the 2016 Kumamoto Earthquake are assessed. Second, objectives are to visualize how an integrated approach of societal groundwater stakeholders can contribute to a sustainable groundwater management. We finalize the paper by outlining how results and experiences in this paper can be used by planners and managers of groundwater resources to build resilient systems for groundwater management through an integrated approach.

Materials and methods

Experimental study area

The total area used for artificial groundwater recharge is about 1200 ha of existing paddy fields in the mid-stream area of the Shirakawa River (Fig. 4). Water for the artificial recharge area is taken from seven weirs (Hata, Uwaide, Shimoide, Sako, Tamaoka, Tsukure, and Babakusu). The location of these weirs and irrigation areas are shown in Fig. 4. In the mid-section area of the Shirakawa River Basin, about 0.6 to 0.8 million m^3 of water are withdrawn from the Shirakawa River during 1 day using these seven weirs. This water volume corresponds to infiltration and evapotranspiration of the artificial recharge area (Ichikawa 2015a). Since evapotranspiration on average is about 5 mm/day in Japan, the loss of water from the 1200-ha paddy field area in the mid-stream of the Shirakawa Basin is up to about several tens of thousands of m^3 (the rice planting area is about 700–800 ha). This means that water corresponding to about 100 mm/day infiltrate on the paddy fields constituting the artificial recharge system. Paddy fields in this area are so called "basket paddy fields", meaning that the under-laying soil structure has a high permeability (Kumamoto Groundwater Workshop and Kumamoto Development Researc Center 2000). The outline of the groundwater flow is shown in Fig. 2. Water infiltrating through the paddy field enters the pyroclastic flow deposits of ASO-2 and ASO-3 type. As the water percolates, it forms groundwater in the second deeper aquifer. After this, groundwater flows horizontally in a southwest direction to the Togawa lava layer. Eventually, groundwater discharges into the Ezuko Lake.

Rice for whole crop silage (WCS) and rice for animal fodder were planted from 2010. The WCS is an unripe rice harvested at the beginning of September and intended as

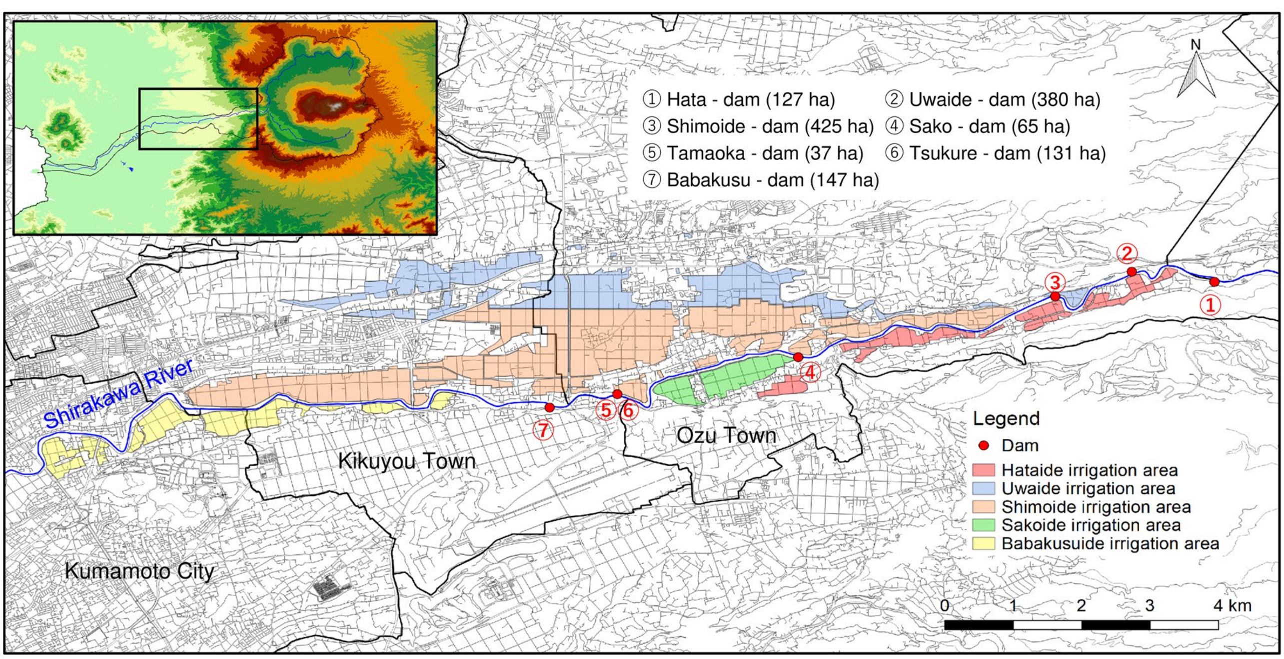


Fig. 4 Location of irrigation weirs and irrigation areas along the mid-stream area of the Shirakawa River

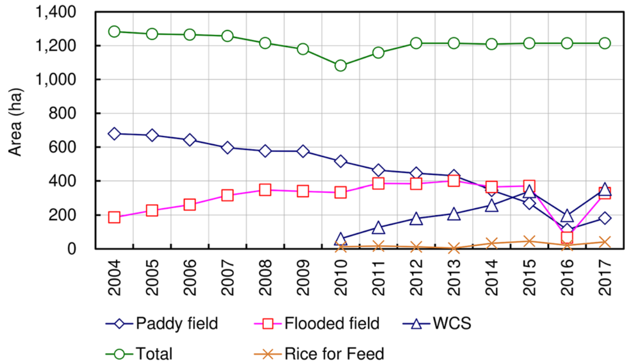


Fig. 5 Area change of paddy fields, flood paddy fields, WCS, and rice for feed (groundwater recharge measures started in 2004 and the Kumamoto earthquake occurred in 2016)

fodder. Fodder rice is matured rice harvested at the end of October. As farmers can receive governmental subsidies by producing WCS as well as by allowing their paddy fields to be flooded during fallow periods, the artificial recharge area has continuously increased from 2004. The planted acreage of WCS was 60.6 ha (5.1% of total 1200 ha paddy field area) in 2010. It increased rapidly to 132.7 ha (11.1%) in 2011, 215.7 ha (18%) in 2013, and 342.2 ha (28.5%) in 2015 (Fig. 5; WCS).

On the other hand, planted rice for feed acreage has not increased substantially. In 2010, it was 12.5 ha (1% of total rice paddy area), 17.1 ha (1.4%) in 2011, 4.7 ha (0.4%) in 2013, and 45.6 ha (3.8%) in 2015 (Fig. 5; rice for feed). Farmers did not increase their profit by growing rice for fodder due to that they then cannot use their fields for flooding. In any case, the cultivation of rice for human consumption in the mid-stream part of the Shirakawa River Basin continues to decrease.

Methods

Water infiltration surveys were conducted to calculate the amount of water recharging the groundwater in the artificial recharge area. In the water infiltration surveys, the water level was recorded depending on time using stakes with scale after flooding and closing the entrance of water to the fields (Fig. 6). Then, daily water infiltration rate was estimated using the inclination of regression line based on decline of water level with time.

In order to evaluate the groundwater recharge for the total artificial recharge area, we investigated the daily infiltration rate of 100 flooded artificial recharge fields and 70 paddy fields. Participating farmers reported duration and extent of flooding and this information was used to calculate daily groundwater recharge volumes (Ichikawa 2017). In the middle of rice cultivation, farmers drain water from the paddy fields. This is generally called "mid-summer drainage".

Fig. 6 Example of measures to increase recharge in the mid-stream of the Shirakawa River Basin

The purpose of the mid-summer drainage is to improve the paddy environment and promote effective growth of rice. In the case of the 70 paddy fields, the infiltration rate is significantly different before and after mid-summer drainage. For this reason, we conducted water infiltration experiments before and after the mid-summer drainage. The evapotranspiration was calculated using the Thornthwaite method (1948) and daily recharge rates were calculated by subtracting the evapotranspiration from the water infiltration rate on a daily basis. A constant evapotranspiration depth was used for the entire artificial recharge area.

Results and discussion

Artificial recharge system before earthquake

Figure 7 shows the total groundwater recharge volume for the entire artificial recharge system in the mid-stream area of the Shirakawa River during 2004–2017 (Fig. 4). The groundwater recharge volume from the recharge system was about 9.2 million m^3 in 2004 (first year), about 10 million m^3 in 2005, and about 20 million m^3 in 2007 (Fig. 7; flooded fields). The increase in artificial recharge was achieved due to a continuous increase in flooded area as described in "Materials and methods". The recharge volume was maintained at about 20 million m^3 from 2007 to 2015 due to an almost constant flooded area (Ichikawa 2015a). The total groundwater recharge volume, thus, includes contributions from WCS, rice for feed, paddy fields, and flooded fields. As seen from Fig. 7, there was a temporary decline in recharge volume during 2012. This was due to a flood event of the Shirakawa River that caused damage to farmland areas.

After 2004 when the artificial recharge project started, the declining groundwater trend (− 0.00024 m/day) changed

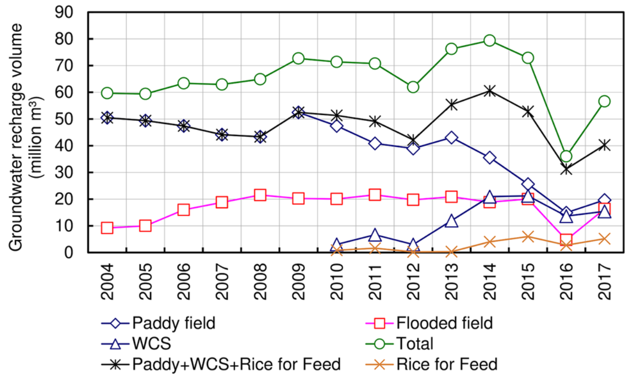


Fig. 7 Annual groundwater recharge volume in paddy, flooded, WCS, and rice for feed (groundwater recharge measures started in 2004 and the Kumamoto earthquake occurred in 2016)

to a slightly increasing trend (+0.00002 m/day) (Fig. 8). The downstream (Ezuko Lake) of the artificial groundwater recharge, system as well, displayed a halt in the declining discharge volumes. During 2005, a minimum discharge from the Ezuko Lake was observed. From 2006 a marked increase was found (Fig. 9). However, from 2008 and onwards, the average discharge was almost constant (Fig. 9) (Ichikawa 2015b).

Precipitation amount is also an important factor for groundwater recharge in the forests and upland fields. Groundwater level showed higher peaks in some years because of higher precipitation amount (Fig. 8). To evaluate the long-term trend in precipitation, Mann–Kendall test was performed using monthly precipitation data from 1992 to 2004 and 2004 to 2017. However, there were no significant upward or downward trends for these periods ($p > 0.05$). Thus, the decline of groundwater level and spring volume to Ezuko Lake was mainly caused by a decline of groundwater recharge due to the Japanese rice production adjustment policy and urbanization. The continuous rise in groundwater level and increase in the amount of spring water to the Ezuko Lake are thus considered to be effects of the established artificial recharge system.

Earthquake damage to the artificial recharge system

As mentioned above, the Kumamoto earthquake on April 14th and 16th, 2016, was followed by torrential rain in June.

Fig. 8 Groundwater level change in the Kumamoto groundwater basin

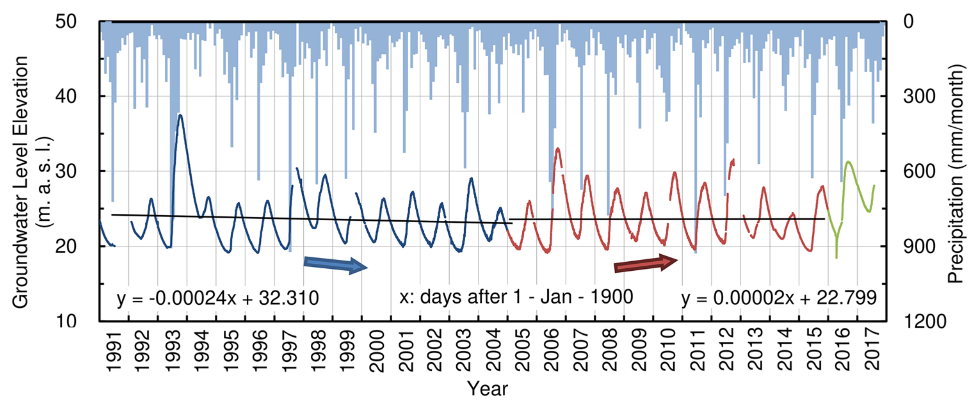
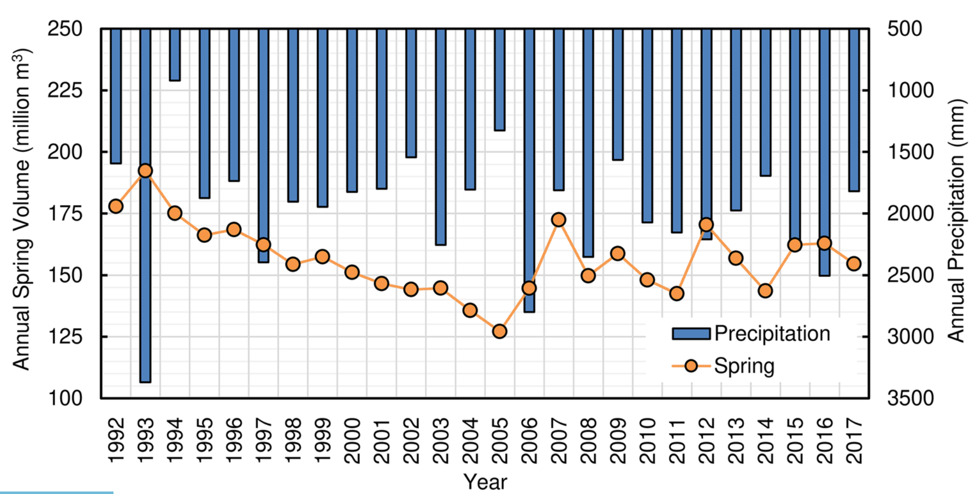


Fig. 9 Annual discharge from the Ezuko Lake and precipitation



The rainfall on June 19–30 was 593 mm. Most of the irrigation channels supplying water to the flooded fields were destroyed by the earthquake and could not supply water for the artificial groundwater recharge. Figure 10 shows an example of the damage that occurred in the Uwaide irrigation channel. The earthquake, as well, damaged irrigation systems in the mid-section of the Shirakawa River Basin at about 70 locations. As a result, it was impossible to take water from the five weirs except from the Hata and Babakusu weirs. In addition, the heavy rainfall caused landslides that buried the Hata irrigation system. Therefore, almost no water was supplied to the irrigation channels and the recharge system. Thus, the area of the artificial recharge system decreased from 386.6 ha in 2015 to 84.4 ha in 2016 (Ichikawa 2016). The amount of recharge from the flooded fields decreased to only 4.71 million m^3 in 2016. This amount was only 23.5% of recharge during the previous year (2015). Because of this situation, the total recharge amount in Shirakawa River Basin decreased to only 49% (36 million m^3 in 2016) compared to the previous year (72.9 million m^3, 2015). As well, most of the agricultural activity stagnated due to the destruction of the irrigation systems.

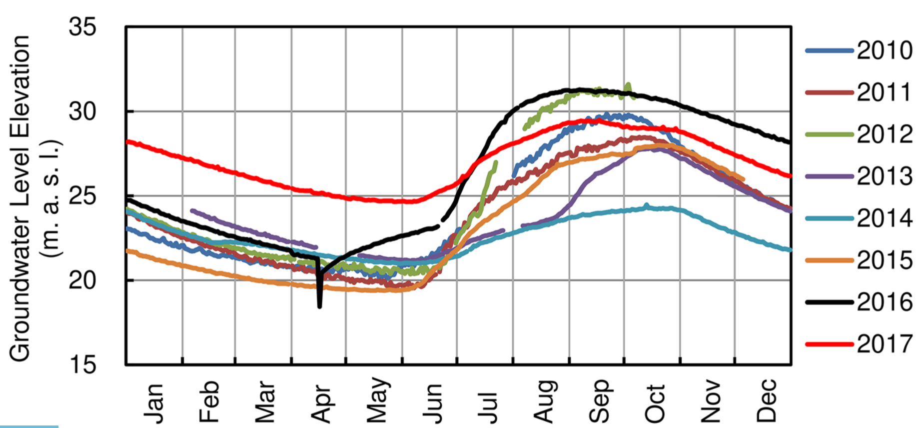
Fig. 10 Example of collapsed irrigation channel in the Shirakawa River Basin

However, an immediate effect of the Kumamoto earthquake was a groundwater level rise of more than 2 m (Fig. 11). This rapidly rising groundwater level was probably caused by a sudden release of stored groundwater along the mountain slopes (Wang et al. 2004; Wang and Manga 2015). Moreover, the groundwater level rose during June–September because of extreme amounts of rainfall, 2653 mm in 2016 (annual mean rainfall was 2205 mm during 2003–2010). Even though there was little groundwater recharge in the basin, the spring discharge to the Ezuko Lake increased substantially as shown in Fig. 9. This was caused by the sudden groundwater level rise after the earthquake.

Artificial recharge system after the earthquake

The system for disaster recovery in Japan is organized according to a centralized method (Ikeda et al. 2008). In the case of the destroyed irrigation channels, this meant that the disaster recovery authorities could take a leading role in organizing the recovery work with participation from all stakeholders involved in the artificial groundwater recharge system. Similarly, much recovery work was done with the help of local farmers participating in the artificial flooding of recharge areas. Due to this approach and participation of all stakeholders, damages to the water channels caused by the earthquake were repaired in a rather short time and emergency re-construction was finished for the irrigation channels in 2017 (about 1 year after the 2016 earthquake). In the following year, almost normal farming activities and artificial recharge were implemented. Thus, water transport to the recharge system was resumed at almost the same level as before the earthquake. The area of flooded fields, WCS, and rice for animal fodder was more or less re-established. In 2017, the recharge area had recovered to 354.2 ha (91.6% of 2015) as shown in Fig. 5. The total groundwater recharge volume decreased to about 16.32 million m^3/year. This volume was 81.4% of 2015 as shown in Fig. 7. As mentioned above, infrastructure such as irrigation channels were recovered and it was possible to store the same amount of

Fig. 11 Examples annual groundwater level changes in the Shirakawa River Basin (Kikuyo observation site)



groundwater as before the earthquake. However, the natural aquifer system such as pore structure of soil and rocks was probably changed by the earthquake. However, we have not yet enough data after the earthquake to analyze these changes.

The above example shows how the resilience of groundwater management and artificial recharge can be strengthened through an integrated approach of all societal groundwater stakeholders. Thus, a sustainable long-term groundwater management can be almost assured. This, on the other hand, requires a political will and active participation by authorities that are willing to set up a policy for long-term visions. Similarly, local stakeholder interaction can be used to strengthen practical research work as shown here with more than 170 recharge observation points operated by local farmers and organized by engaged researchers.

Conclusions

Due to decreasing groundwater levels in the Shirakawa River Basin, an artificial groundwater recharge system was established in 2004. The system was built on an integrated collaboration between administration, private groundwater using companies, researchers, and local farmers. In 2015, a volume of about 20 million m^3 groundwater recharge was achieved. As a result, the declining trend for the groundwater table was reversed, the downstream spring water amount increased, and the artificial groundwater recharge system showed good efficiency. The 2016 Kumamoto earthquake, however, damaged much of the water transport infrastructure that supplied water to the recharge system. The area of the artificial recharge was reduced from 386.6 ha (2015) to 84.4 ha (2016) after the earthquake. The groundwater recharge volume from flooded fields decreased to 4.71 million m^3 only (23.5% of the previous year 2015). And the total groundwater recharge volume in the mid-stream of the Shirakawa River Basin was reduced to 36 million m^3 (49.4% of the previous year 2015). Even so, the observed groundwater level and spring discharge from the Ezuko Lake did not decrease. The reason for this was probably due to sudden drainage of water during the earthquake from the mountain region and heavy rainfall during June to September. The destroyed water channels and agricultural facilities were, however, repaired in just 1 year, and by 2017 the area of recharge system was restored to 91.6% of pre-earthquake conditions groundwater recharge volume recovered to 16.32 million m^3.

The presented study shows that a combined effort from authorities, private companies, researchers, and local farmers can create a sustainable artificial groundwater recharge system of regional importance. The Kumamoto region is the largest consumer of groundwater in Japan. Thus, it is important to supply and replenish upstream areas with recharging water. As the upstream surface area use gradually changed away from traditional paddy rice field farming to vegetables and other non-ponding agriculture, the groundwater recharge continuously declined. This resulted in a severe downstream groundwater decline. As a result, an artificial groundwater recharge system was established in 2004. The supply system to the recharge area was to a great extent destroyed in 2016 by the Kumamoto earthquake. The resilience of the system was, however, seen by the fast restoration in only 1 year. Thus, it can be stated that the recharge system and groundwater management are sustainable in the long-term.

The experiences from this study can be used in other areas where declining groundwater levels are observed. The results show that a joint venture between authorities, private interests, and local farming can provide an efficient organization for managing artificial recharge systems. As seen from the results in this paper, the resilience of the system was quite strong even in the case of a major earthquake. Results and experiences outlined in this paper can be used by planners and managers of dwindling groundwater resources to build resilient systems for groundwater recharge and use involving all societal stakeholders through an integrated approach.

References

Alley WM (2009) Ground water. In: Likens GE (ed) Encyclopedia of inland waters. Academic Press, New York, pp 684–690. https://doi.org/10.1016/B978-012370626-3.00015-6

Goto Y, Suzuki T, Suetomi I, Shoji Y, Tsuruta M, Kataoka S, Suzuki H (2007) Research for mitigation of damage caused by interdependencies among critical infrastructure. Proc JSCE Earthq Eng Symp 29:1344–1354 **(in Japanese with English abstract)**

Hida N (2002) Experiences and forward-looking view of artificial recharge of ground water. J Jpn Assoc Hydrol Sci 32(3):63–70 **(in Japanese)**

Ichikawa T (2014) Influence to Groundwater by the flooding water project in the Middle-Shirakawa River Area, Kumamoto. Bull Sch Ind Welf Eng Sch Ind Eng Tokai Univ 2:1–6

Ichikawa T (2015a) The effect evaluation report by filling water in the middle area of the Shirakawa River in fiscal year 2015. Tokai University, Kumamoto

Ichikawa T (2015b) Evaluation of groundwater recharge in the mid-stream area of the Shirakawa River in fiscal year 2015. Tokai University, Kumamoto

Ichikawa T (2016) Evaluation of groundwater recharge in the mid-stream area of the Shirakawa River in fiscal year 2016. Tokai University, Kumamoto

Ichikawa T (2017) Evaluation of groundwater recharge in the mid-stream area of the Shirakawa River in fiscal year 2017. Tokai University, Kumamoto

Ichikawa T, Ito Y, Mekprukasawong P (2013) Nitrate nitrogen pollution by recharge in agricultural area in Kumamoto area, Japan. Internet J Soc Soc Manag Syst 9(1):SMS13-5572

Ikeda S, Sato T, Fukuzono T (2008) Towards an integrated management framework for emerging disaster risks in Japan. Nat Hazards 44:267. https://doi.org/10.1007/s11069-007-9124-3
Kataoka S, Shirato S, Ushijima Y, Takamiya S (2013) Modeling and simulation of disaster recovery process of infrastructure system. J JSCE Ser A1 (Struct Eng Earthq Eng) 69(1):1–19 **(in Japanese with English abstract)**
Kiriyama T, Ichikawa T (2004) Preservation of groundwater basin recharging by paddy field. J Hydraul Eng 48:373–378
Kumamoto Foundation Society (2010) Cross sectional geological features in the Kumamoto area. Kumamoto Ground Water Foundation, Kumamoto
Kumamoto Groundwater Workshop and Kumamoto Development Research Center (2000) History of groundwater observations and research in the Kumamoto area: Kumamoto area groundwater research report. Kumamoto Groundwater Workshop and Kumamoto Development Research Center, Kumamoto
Kumamoto Prefecture and Kumamoto City (2005) Report on groundwater conditions in the Kumamoto Area, Kumamoto Prefecture and Kumamoto City, Kumamoto
Kumamoto Prefecture (2008a) Kumamoto area groundwater overall maintenance and management plan. Kumamoto Prefecture. https://www.pref.kumamoto.jp/kiji_574.html. Accessed 29 Feb 2020
Kumamoto Prefecture (2008b) Kumamoto data sheet of water resources. Land of Water Kumamoto. https://mizukuni.pref.kumamoto.jp/one_html3/pub/default.aspx?c_id=16. Accessed 18 Dec 2019
Kumamoto Prefecture (2012) Changed Kumamoto-prefecture groundwater protection regulation. Land of Water Kumamoto. http://mizukuni.pref.kumamoto.jp/one_html3/pub/default.aspx?c_id=6. Accessed 29 Feb 2020
Pyne RDG (1995) Groundwater recharge and wells—a guide to aquifer storage recovery. Lewis Publishers, Boca Raton
Signor DC, Growitz DJ, Kam W (1970) Annotated bibliography on artificial recharge of ground water, 1955–67: U.S. geological survey water supply paper 1990. United States government printing office, Washington
Takemori Y, Ichikawa T (2009) On effect of groundwater recharge evaluation by keeping water in no use paddy field in the middle Shira-River area. Bull Sch Ind Eng Tokai Univ 1:53–59
Thornthwaite CW (1948) An approach toward a rational classification of climate. Geogr Rev 38(1):55–94
Todd DK (1959) Annotated bibliography on artificial recharge of ground water through 1954: U.S. geological survey water-supply paper 1477. United States government printing office, Washington
U.S. Geological Survey (2002) U.S. geological survey artificial recharge workshop Proceedings, Sacramento, California, April 2–4, 2002: U.S. geological survey open-file report 02-89
Wang C-Y, Manga M (2015) New streams and springs after the 2014 Mw6.0 South Napa earthquake. Nat Commun 6:7597
Wang C-Y, Wang C, Manga M (2004) Coseismic release of water from mountains: evidence from the 1999 (Mw = 7.5) Chi-Chi, Taiwan, earthquake. Geology 32(9):769–772
Yoshizawa G, Tatano H, Hatayama M (2018) Water demand management for disaster preparedness through risk communications. J JSCE Ser D3 Infrastruct Plan Manag 74(1):35–49 **(in Japanese with English abstract)**