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Regional characteristics of water use system in the Ashida River Basin in terms of water supply and demand balance

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Abstract

This study analyzed the regional characteristics of water supply and demand in the Ashida River Basin in Hiroshima Prefecture. Chronological changes of water demand in Fukuyama City, the biggest downstream city, and countermeasures for water shortages were also clarified, in order to discuss sustainable water utilization systems. The Ashida River Basin has relatively high ratio of water demand against the water resource capacity of the basin. Under the current circumstances in which the majority of the water demand is dependent on the surface water developed by dam construction, focusing on accessible water sources such as groundwater and local reservoirs and promoting their maintenance and effective utilization become more and more important for a sustainable water utilization system.

Key words: water use system, water supply and demand, river basin, the Ashida River

1. Introduction

Located in the Asian monsoon region in the temperate zone, Japan has a relatively high precipitation compared to the rest of the world. Meanwhile, due to its high population density, advanced industrialization, and well-developed rice paddy cropping, the country has significantly high water demand. Furthermore, rivers in Japan are known for their steepness compared with rivers around the world, while not having aquifers with sufficient capacity. Therefore, water for agriculture, industry, and residential uses is dependent on surface water such as rivers, lakes, and swamps. This has resulted in enhanced water resources development in each region of Japan by the construction of dams and estuary weirs, throughout the industrialization and population increase era in the modern period.

After the 1980s, however, the gross water demand of Japan fell from static to decreased condition, due to the decline of agriculture and industry, as well as popularization of water saving technologies. Along with this, the water resource policy also shifted from development of new water sources in response to increased demand, to reorganizing of existing water sources according to the stagnating or decreased demand. The focus was also shifted to accommodation of water resources during the times of extraordinary droughts or disasters (Yamashita, 2013a). One of the measures for adapting water resources that had been discussed is the diversion of agricultural water to municipal water (Akiyama, 1988). In recent years, ground water has also been paid much attention as an alternative water source for a case of emergency (Hiroki, 2010).

By the way, it is important to focus on the spatial scale of river basins, when discussing water supply and demand, and water usage systems. Yamashita (2007, 2009) conducted a comparative analysis of agricultural water usage systems and municipal water systems in several regions in Northern Kanto Region, and discussed them in relation to the environmental conditions of the basins. Yamashita (2013b) calculated water supply and demand of 109 major river basins in Japan and analyzed the regional characteristics comparatively.

With this in mind, regional characteristics of water supply and demand at the basin level were analyzed in this study for the Ashida River Basin in Hiroshima Prefecture. Chronological changes of water demand in Fukuyama City, the biggest downstream city, and countermeasures for water shortages were also clarified, in order to discuss sustainable water utilization systems. The Seto Inland Sea Region, where the Ashida River Basin is located, is known for its relatively low precipitation in Japan, while population and industries have been traditionally concentrated in the region to some extent. This region is the pioneering and the representative region for succeeding water resource diversion from agricultural water to municipal water during the time of increased water demand (Shirai, 1979; Akiyama, 1980).

2. Relative characteristics on water supply and demand balance in the Ashida River Basin

The Ashida River flows about 86km from its water source in Kuramune, Mihara City in Hiroshima Prefecture (formerly Daiwa Town) into the Seto Inland Sea at Fukuyama City, via the Sera Plateau, Fuchu City, and Kannabe Plain (Fig. 1). The major municipalities composing the river basin are Sera Town, Fuchu City, and

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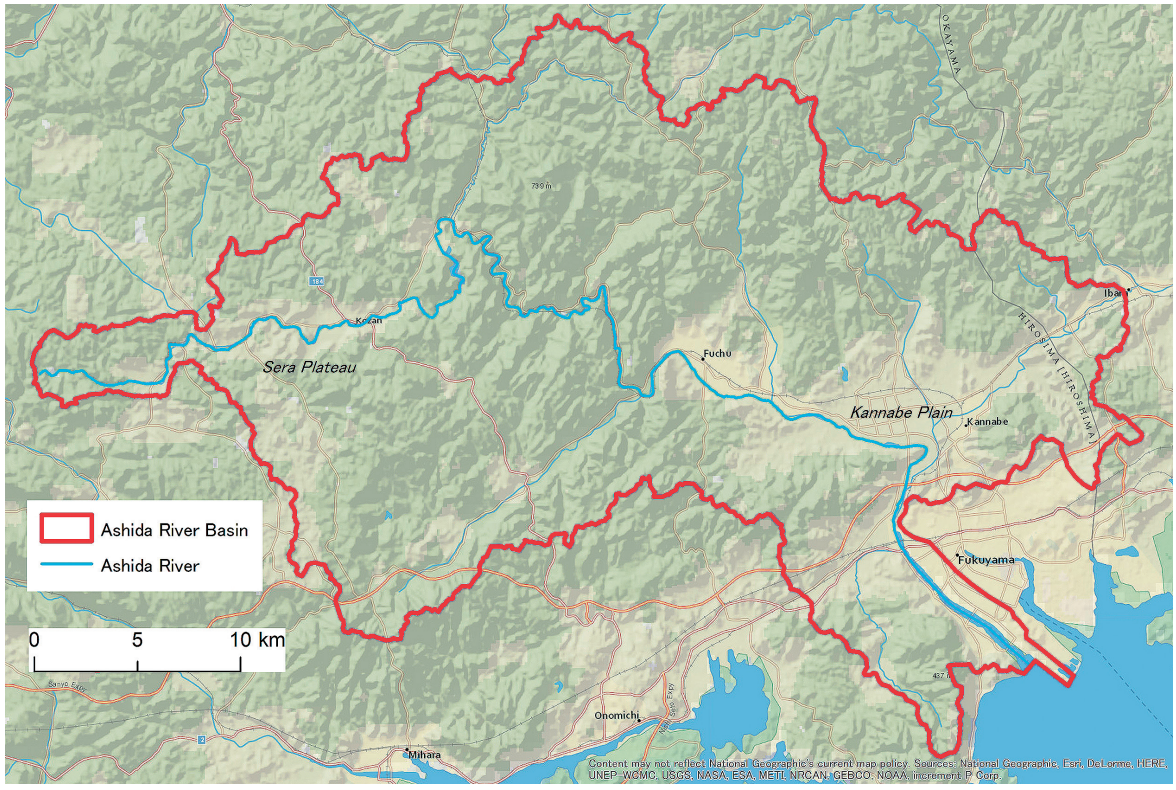

Fig. 1 The outline of the Ashida River Basin

Sources: National Geographic, ESRI, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Fukuyama City from upstream to downstream. The basin also includes Mihara City, Onomichi City, and Jinsekikogen Town, as well as Ibara City and some part of Kasaoka City in Okayama Prefecture. A manor of Mt. Koya (Koya-san Temple) used to be located in the Sera Plateau, and the area is still an active rice cropping region today. A basin called the Kannabe Plain in the northern part of Fukuyama City is also an active rice cropping area, but conversion to a residential area has been progressing in recent years.

Based on the water supply and demand database of 109 major river basins in Japan developed by Yamashita (2013b), characteristics of water supply and demand of the Ashida River Basin were relatively comprehended. Table 1 shows trial calculation of the gross water demand, annual precipitation, and water supply and demand ratio in the 1980s and 2000s of the Ashida River Basin. The gross water demand is the sum of water demand for residential, industrial and agricultural uses. The residential water demand was calculated from the population of the basin multiplied by the annual water usage quantity per capita (from Water Resources Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT) ed., 2012). The industrial water demand was calculated from water usage per factory (from the official website of the Ministry of Economy, Trade and Industry) multiplied by the number of manufacturing factories in the basin. The agricultural water demand was calculated by using data from MLIT. The data included rice paddy areas, farmland areas, and agricultural water usage of nine regions, from Hokkaido to Kyushu. However, only nationwide data of the agricultural water usage for different land uses (rice paddies and farmlands) was available. Therefore, based on the nationwide data of the agricultural water usage for different land uses, a water usage ratio of rice paddies and

Table 1 Water supply-demand characteristics of the Ashida River Basin

gross water demand	395,193 (thousand m^3/year)
	354,779 (thousand m^3/year)
annual precipitation	1,393 (mm)
	1,211 (mm)
water supply-demand ratio	57
	67

upper column: 1980s
lower column: 2000s
Source: Yamashita (2013b)

farmlands was calculated first. By using the ratio, the agricultural water usage of each region was then separated into water usages for rice paddies and for farmlands. Each separated value was then divided by the rice paddy area and the farmland area of each region, in order to obtain the agricultural water usage per unit area for each region and use. Finally, the value was multiplied by the rice paddy area and farmland area of the basin to estimate the agricultural water demand of the basin. The precipitation was calculated from mesh data of the digital national land information. The water supply and demand ratio is a ratio of the gross water demand to the amount of available water resource (i.e., precipitation minus evapotranspiration amount).

The gross water demand of the Ashida River Basin was slightly declined over 20 years from the 1980s to the 2000s, while precipitation also decreased. In contrast, the water supply and demand ratio increased from 57 to 67. This means that the decreased ratio of precipitation (supply) was larger than the decreased ratio of demand.

Are these values greater or smaller compared with other river basins in Japan? Based on the gross water demand per area of each basin shown by Yamashita (2013b), it can be said that the water demand of the Ashida River Basin is close to the national average, while categorized into a group with somewhat greater demand than the average. In terms of annual precipitation, the Seto Inland Sea Region including the Ashida River Basin is categorized into a region with relatively low precipitation, along with Hokkaido and the Pacific Ocean side of Tohoku Region. Within Hiroshima Prefecture, the eastern part including the Ashida River Basin tends to have less precipitation than the western part. As for the water supply and demand ratio, the Ashida River Basin is the highest in Chugoku Region, and the tenth highest in Japan. This indicates that the basin has relatively high water demand compared to water supply. The relatively high water demand is caused by the relatively low precipitation and the traditionally active rice cropping at the upstream and the midstream areas of Ashida River; and the existence of Fukuyama City downstream, the second largest city of Hiroshima Prefecture and an active industrial city.

3. Spatial distribution of water supply and demand in the Ashida River Basin

In order to comprehend the spatial distribution of water demand within the Ashida River Basin, the population distribution from the census mesh statistics is shown (Fig. 2). The areas with larger population and greater residential water demand are the central part of Fuchu City locat-

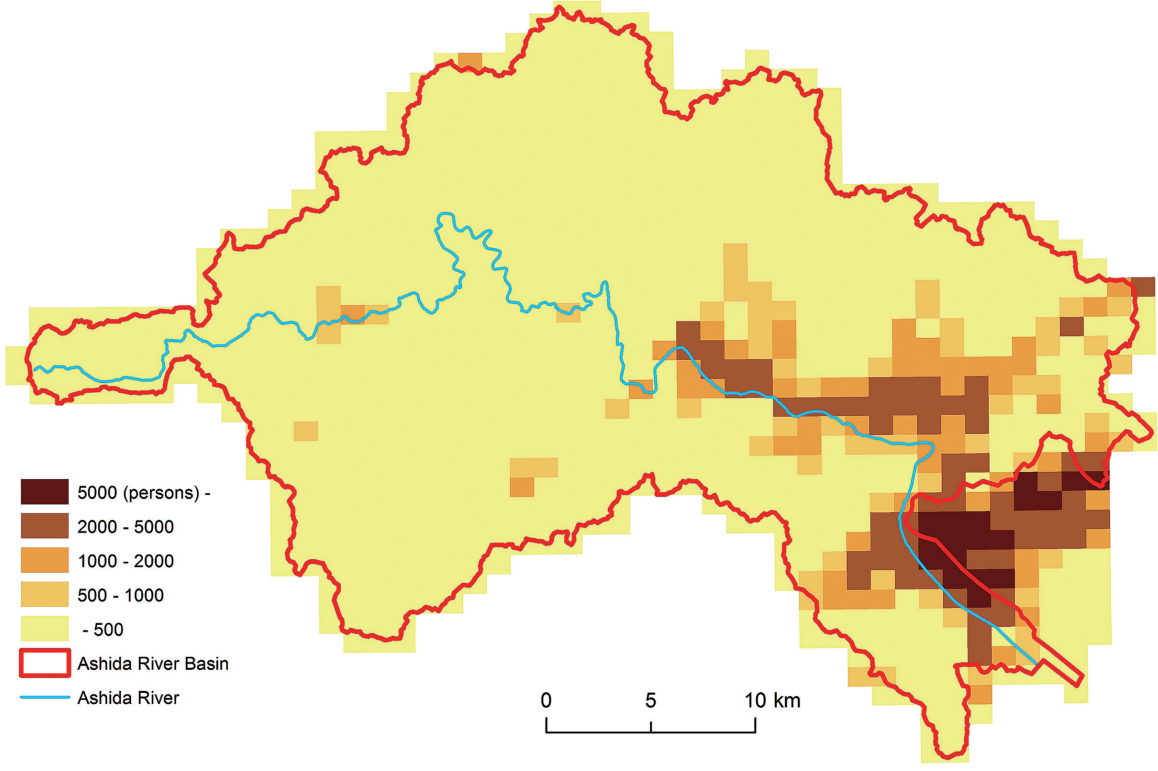

Fig. 2 Population distribution by mesh unit in the Ashida River Basin (2005)

Source: census mesh statistics

ed at the midstream, and the urbanized area of Fukuyama City located at the furthest downstream[1]. Fig. 3 shows the estimate of the annual agricultural water demand calculated by the rice paddy area and farmland area from the land use mesh data of the digital national land information. The meshes with greater water demand are found in the Sera Plateau area at the furthest upstream. The agricultural water demand is also high in the Kannabe Plain at the midstream and downstream.

Next, water rights, which are rights for river water intake, are analyzed. The list of the large-scale specified water utilization[2] (Table 2) includes three specified residential water rights: one in Fuchu City and two in Fukuyama City. Two specified industrial water rights are located in Fukuyama City at the furthest downstream. There are five specified agricultural water rights: three for irrigating rice paddies in Fuchu City at midstream area, one for irrigating in the Kannabe Plain in Fukuyama City, and one for irrigating the delta area and reclaimed land at the furthest downstream. All of them are taken from the main stream of the Ashida River, and the water sources for many of them are the Mikawa dam, Hattabara dam, and the estuary weir of the Ashida River.

Other approved water rights of the main stream and major tributary basins were aggregated for each use (Fig. 4). In addition to the main stream of the Ashida River, small tributaries in the uppermost part as well as the Takaya River, the Kaya River, and the Mitsugi River, are used mainly as agricultural water sources. Rivers in the Basins of the Yamada River, Kanzaki River, and Seto River are also used as residential water sources.

Nonetheless, the total of the specified water rights exceeds 10m^3/sec, while that of these other approved water rights is less than 2m^3/sec. Therefore, it can be said that river water usage in the Ashida River Basin is highly dependent on the main stream.

4. Increase of urban water demand in Fukuyama City

Now, the residential water supply and demand in Fukuyama City is analyzed as the urban water use of the furthest downstream location. Fig. 5 shows the transition of the waterworks coverage ratio and supplied population in Fukuyama City. Figs. 6-8 respectively show transitions of the water intake amount by water source, water supply capacity, and annual water distribution amount / maximum daily water distribution amount since the establishment of the Waterworks in Fukuyama City to the present. Based on those figures, and Editorial Committee of Waterworks History in Fukuyama City ed. (1968) and Waterworks Bureau of Fukuyama City ed. (1991), the transition of

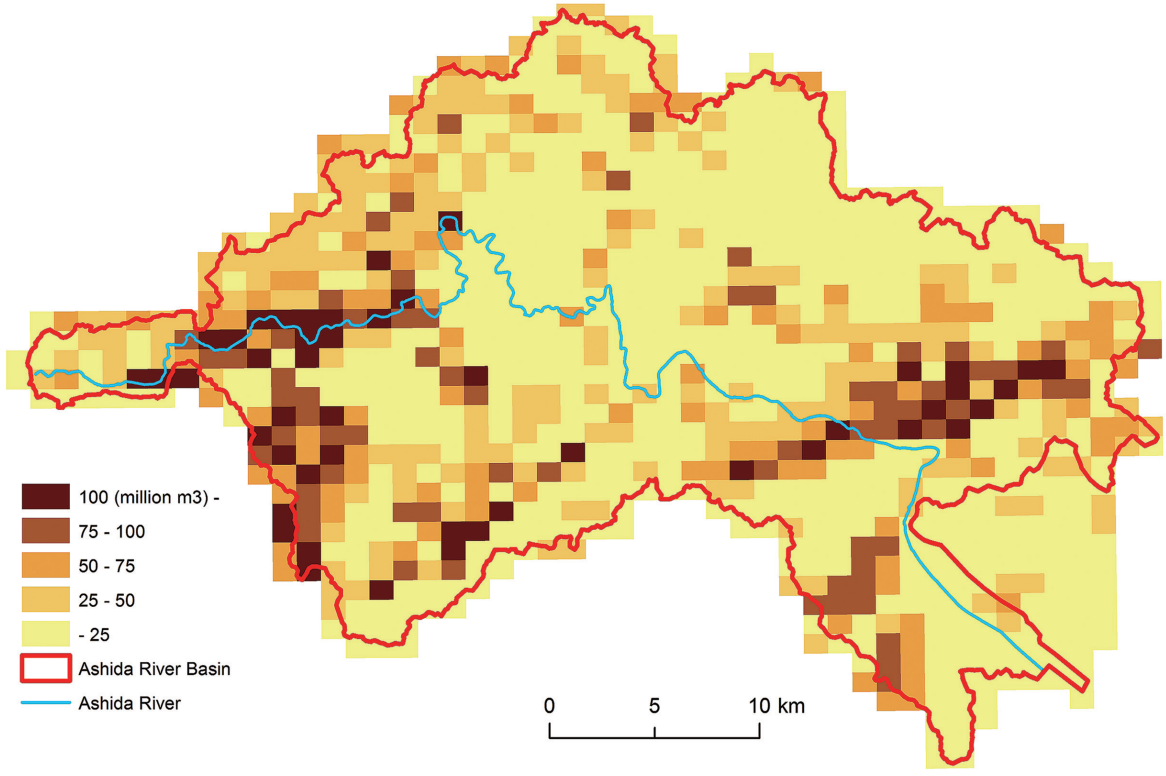

Fig. 3 Annual agricultural water demand by mesh unit in the Ashida River Basin (2006)

Sources: the digital national land information and so on

Table 2 Specified water rights on the Ashida River Basin (2014)

name	purpose	municipality	river	water source	approved quantity of water intake (m^3/s)
Fukuyama waterworks (Nakatsuhara)	residential	Fukuyama City	Ashida River	Hattabara dam, Mikawa dam	2.166
Fukuyama waterworks (Idehara)	residential	Fukuyama City	Ashida River	underflow water	0.465
Fuchu waterworks	residential	Fuchu City	Ashida River	Mikawa dam, river water, underflow water	0.167
Fukuyama industrial waterworks	industrial	Fukuyama City	Ashida River	river water, Mikawa dam, Hattabara dam	2.084
Fukuyama industrial waterworks	industrial	Fukuyama City	Ashida River	Ashida River Estuary Weir	1.968
Ashidagawa irrigation canal (Nanayashiro)	agricultural	Fukuyama City	Ashida River	Mikawa dam	1.587
Imizo irrigation canal	agricultural	Fukuyama City	Ashida River	Mikawa dam	1.339
Rokujizo irrigation canal	agricultural	Fuchu City	Ashida River	Mikawa dam	0.273
Gokason irrigation canal	agricultural	Fuchu City	Ashida River	Mikawa dam	0.545
Chiishi-oidezeki irrigation canal	agricultural	Fuchu City	Ashida River	river water	0.129

Source: material from Fukuyama River and National Highway Office

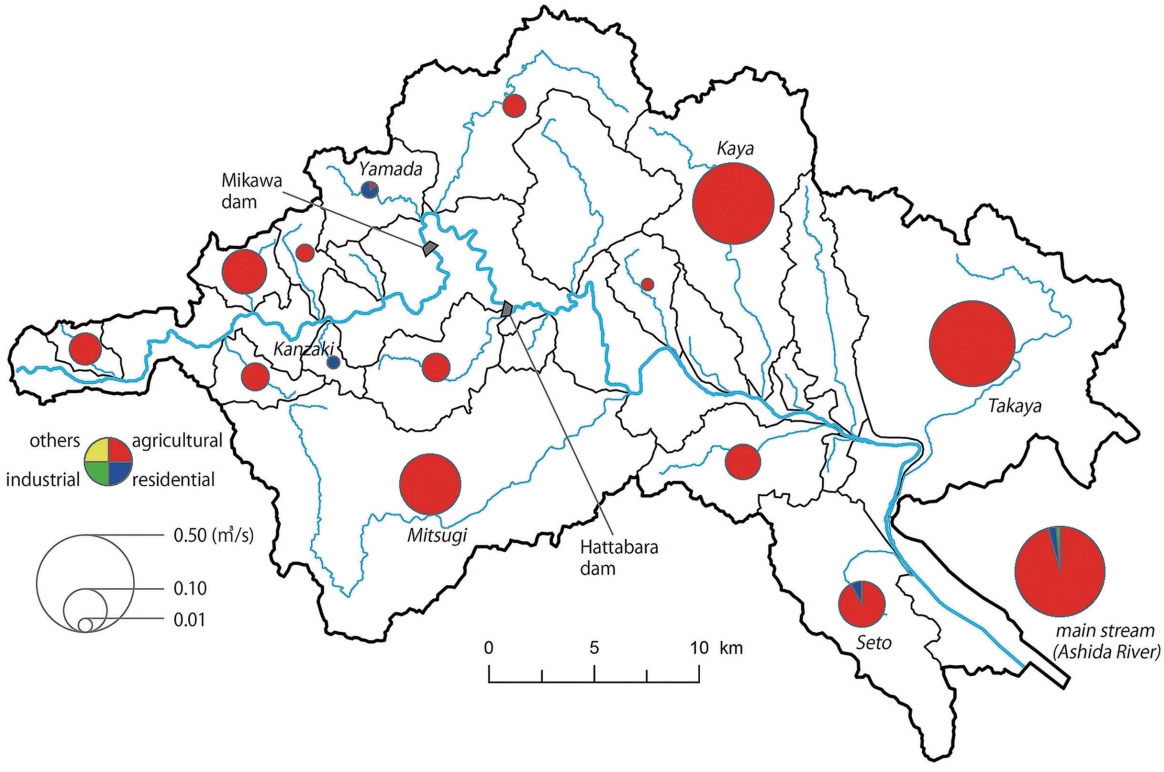

Fig. 4 Total approved water intake by tributary basin and main stream in the Ashida River Basin (2014)

Source: material from Road and River Managemant Section of Hiroshima Prefecture

water demand and supply capacity of the Waterworks in Fukuyama City was clarified.

The Waterworks of Fukuyama City began operation in November 1925, by using the Ronden River, a branch of the Seto River, as a water source at that time. Annual water intake was about 420,000m^3, and the facility capac-

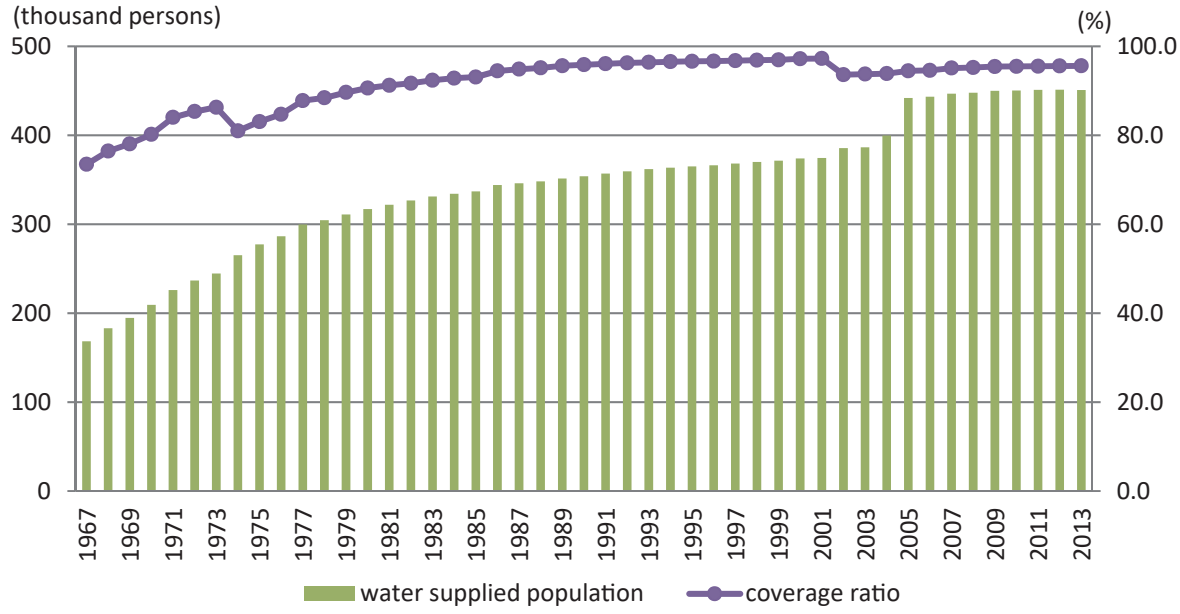

Fig. 5 Transition of water supplied population and coverage ratio in Fukuyama City

Sources: materials from Waterworks and Sewerage Bureau of Fukuyama City

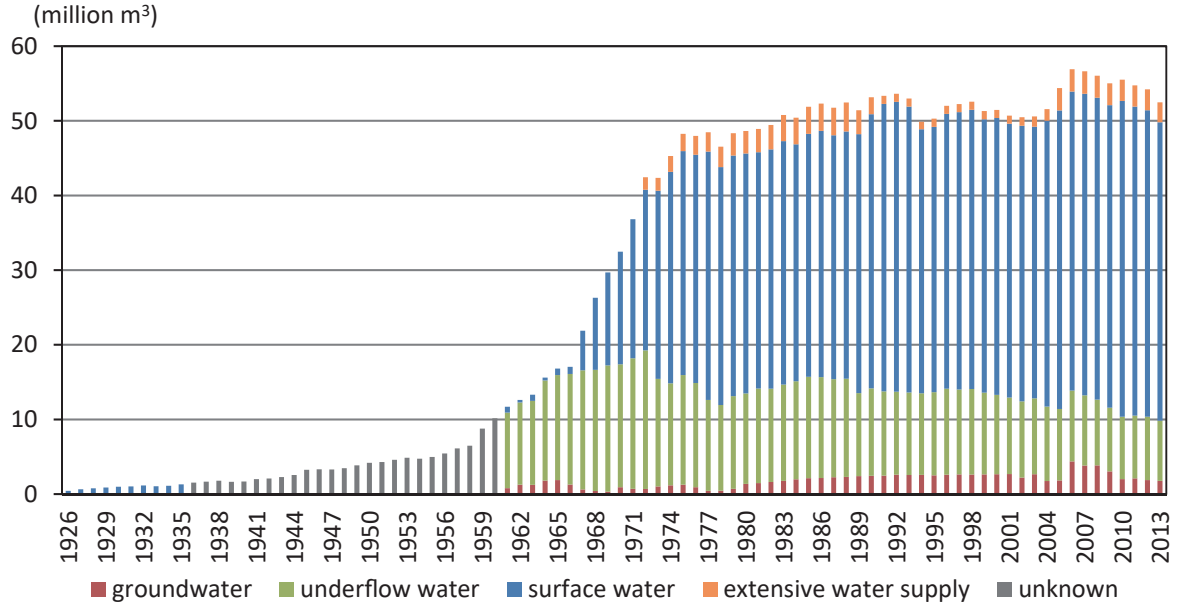

Fig. 6 Transition of water intake amount of Waterworks in Fukuyama City by water source

Sources: materials from Waterworks and Sewerage Bureau of Fukuyama City

ity was 6,250 m^3/day. In 1936, water intake from subsoil flow of the main stream of Ashida River began, along with the first expansion project. After the World War II, the second expansion project was launched in 1951 and the excavation works for three shallow wells were conducted as the new water sources. Consequently, the water intake, facility capacity, and water delivery of Waterworks in Fukuyama City gradually increased. As of 1959, when Idehara water purification plant began operation, these amounts became 8,760,000m^3/year, 40,000 m^3/day, and 8,510,000m^3/year, respectively.

The water demand of Fukuyama City rapidly increased

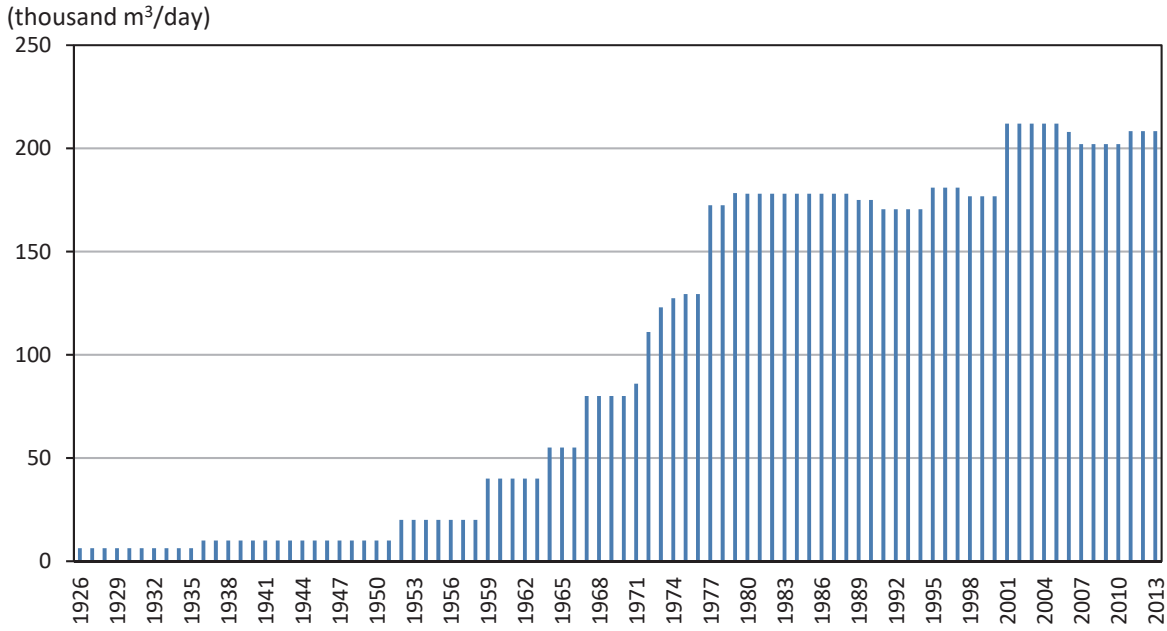

Fig. 7 Transition of water supply capacity of Waterworks in Fukuyama City

Sources: materials from Waterworks and Sewerage Bureau of Fukuyama City

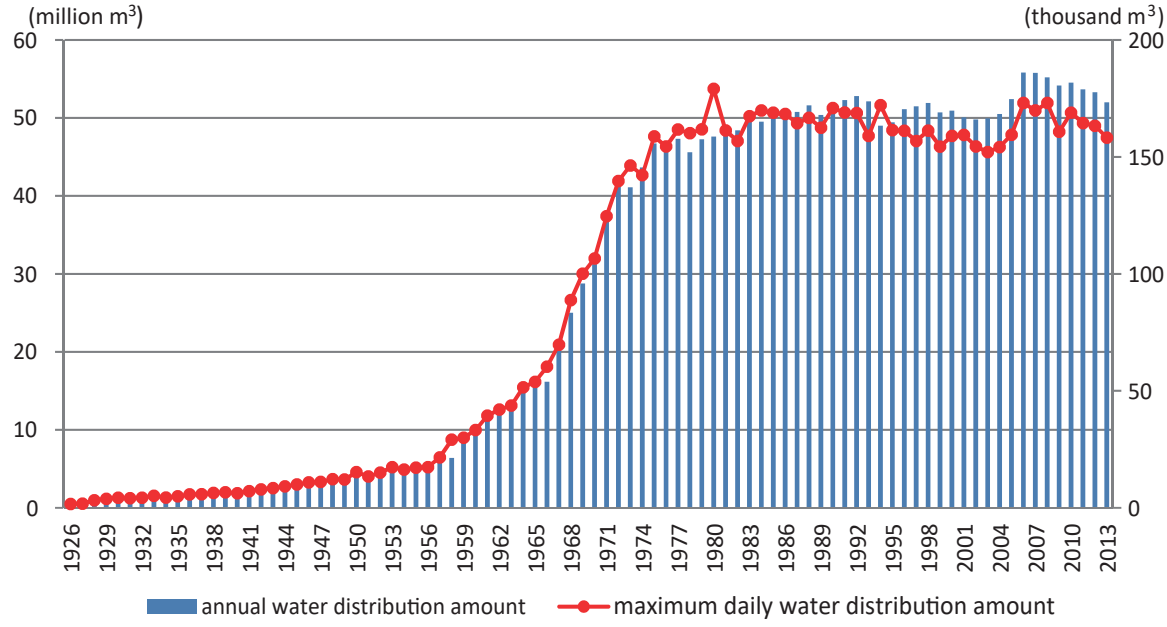

Fig. 8 Transition of water distribution amount of Waterworks in Fukuyama City

Sources: materials from Waterworks and Sewerage Bureau of Fukuyama City

from 1960 to the mid-1970s during the high economic growth period. Of special note during this period was the expansion of Nippon Kokan Ltd. (currently JFE Steel Corporation) to Fukuyama City. Combined with residential land development of the surrounding areas associated with the expansion, the demand for industrial and residential water rapidly increased. In 1967, Nakatsuhara water purification plant was built in response to the increasing demand, and began intake of the surface water from the Ashida River as the water source. Furthermore, with the extension of Mikawa dam, which is located at the upstream of the Ashida River and used exclusively for

agricultural water supply, the waterworks newly gained the water right from excessive agricultural water and increased available water resulting from the extension of Mikawa dam. In addition, water supply from the extensive water supply system of Hiroshima Prefecture began in 1971 when Fukuyama City merged with Matsunaga City. These resulted in the facility capacity of 172,400 m^3/day in 1977 when the fifth expansion project was completed, while the annual water distribution amount increased from 9,760,000m^3 in 1960 to 47,320,000m^3 in 1977. The waterworks coverage ratio steadily increased, except for the temporal decrease in 1974 when Fukuyama City merged with Ashida Town, Kamo Town, and Ekiya Town. The coverage ratio exceeded 90% in 1980.

After the 1980s, the water supply and demand tended to remain at the same level. Hattabara dam, which is regarded as the last water resource development for the Ashida River Basin, was completed in 1998. Accordingly, Senda water purification plant was newly built in 2001 and began operation in 2004. According to the breakdown of the water rights by water source in 2013, groundwater and subsoil flow is 18.8%, water supply from the extensive water supply system of Hiroshima Prefecture is 5.2%, and river water is 76.0%. Most of the river water is from the water sources contributed by the Mikawa and Hattabara dams.

5. Recent water shortage and its countermeasures

Completion of Hattabara dam in 1998 has increased the water utilization stability of the Ashida River Basin. However, water shortage often occurs even in recent years, causing water intake restriction (Table 3). Ashida River Drought Adjustment Council has been organized, led by the Fukuyama River and National Highway Office as the executive office. The council members include: MLIT, Hiroshima Prefecture, Fuchu City, Fukuyama City, Onomichi City, Sera Town, and major water users (municipal waterworks bureaus, land improvement districts, and electric power companies). In addition to an annual regular meeting, special meetings are held during the period of water shortage to discuss restriction of water intake, its period and intensity of restriction, etc. According to Table 3, industrial and agricultural water intake was restricted twice during 2008 to 2009, and also in 2011 and 2013. In 2009, agricultural water intake was largely restricted in the tributary, Yamada River. Furthermore, Fukuyama City located at the furthest downstream independently conserves industrial and agricultural water, aside from the water intake restriction by the council. However, residential water use was never restricted in any cases.

Countermeasures have been provided by water users for the cases of water shortage. A business establishment in Fukuyama City, using river water for industrial water, constructed wells as the supplemental water source within the site. Some other plants have achieved high circulation rate by repeatedly using intake water for coolant of machines, and some have even equipment not requiring cooling water at all for coolant of machines. When agricultural water intake restrictions are implemented, periods with higher water demand (rice planting season in early June and ear emergence season in early August) are avoided as much as possible, as Table 3 indicates. In some cases, water is kept in irrigation canals, like creeks, in order to promote effective water utilization. The Waterworks and Sewerage Bureau of Fukuyama City, one of

Table 3 Recent restriction of water intake in the Ashida River Basin

period (y/m/d)	purpose and intensity	scope
2007/12/5-2008/2/4	industrial: 10%, agricultural: 50%	Fukuyama City
2008/10/3-2008/11/17	industrial: 10%, agricultural: 10%	Fukuyama City
2008/11/18-2009/3/16	industrial: 20%, agricultural: 20%	Ashida River Drought Adjustment Council
2009/3/17-2009/6/1	industrial: 10%, agricultural: 10%	Fukuyama City
2009/6/2-2009/6/14	industrial: 20%	Ashida River Drought Adjustment Council
2009/6/15-2009/7/23	industrial: 30%, agricultural: 30%	Ashida River Drought Adjustment Council
2009/6/10-2009/6/22	agricultural: 40%	Yamada River Drought Adjustment Council
2009/6/23/2009/7/2	agricultural: 60%	Yamada River Drought Adjustment Council
2011/3/19-2011/4/14	industrial: 10%, agricultural: 10%	Ashida River Drought Adjustment Council
2011/4/15-2011/5/13	industrial: 20%, agricultural: 20%	Ashida River Drought Adjustment Council
2013/5/31-2013/6/10	industrial: 10%, agricultural: 10%	Fukuyama City
2013/6/11-2013/6/20	industrial: 20%, agricultural: 20%	Ashida River Drought Adjustment Council

Source: material from River Section of Hiroshima Prefecture

the major water users, constructed three shallow wells in Nakatsuhara water purification plant. Those three wells, unused in normal times, can pump up about 10,000m^3/day a total and the water can be used after it is purified at the water purification plant. Other emergency water sources include about 130 small reservoirs within the city, and 20,000 drinking water bottles (490ml) stocked at Senda water purification plant.

6. Discussion and conclusion

This study analyzed the spatial characteristics of the water supply and demand balance in the Ashida River Basin, and revealed the trend of water demand in Fukuyama City at the furthest downstream location, along with the countermeasures against recent cases of water shortage. Finally, from a standpoint of sustainable water utilization systems, its remarkable points and propositions were discussed.

Compared with other river basins in Japan, the Ashida River Basin has relatively high ratio of water demand against the water resource capacity of the basin. In addition, the water demand is highly dependent on the main stream. In particular, the Waterworks in Fukuyama City is extremely dependent on the dams provided on the main stream. In the river basin with such a relatively strained balance of water supply and demand, high reliance on the specific water source cannot be considered as very sustainable. On the other hand, the city does not rely much on the extensive water supply system of Hiroshima Prefecture, which intakes water from other river basins. In this regard, it fulfills the water demand by local water sources found in its own basin.

Because of the improved water utilization stability after the completion of Hattabara dam, residential water intake restriction has been avoided during the period of water shortage, and even the agricultural water intake has been adjusted to avoid water intake restrictions during rice planting and ear emergence seasons as much as possible. Nevertheless, it is necessary to ensure sufficient alternative water sources in cases of water shortage and natural disasters. Under the current circumstances in which the majority of the water demand is dependent on the surface water developed by dam construction, focusing on accessible water sources such as groundwater and local reservoirs and promoting their maintenance and effective utilization become more and more important for a sustainable water utilization system.

Notes

1) The urbanized area of Fukuyama City is actually located outside of the basin, while the area is highly distributed the water from the Ashida River.
2) Specified water utilization means residential water rights over 2,500m^3/day of the maximum water intake or over 10,000 of water supplied population, industrial water rights over 2,500m^3/day of the maximum water intake, agricultural water rights over 1m^3/sec. of the maximum water intake or over 300ha of the irrigation area, or water rights for hydraulic power generation.

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