Research article

Evaluation of Oxbow Lakes and Circulating Irrigation in the Ishikari River Basin, Japan

DAISUKE KUSA*
Tone River Basin Research and Management Office, Kanto Regional Agricultural Administration Bureau, Ministry of Agriculture, Forestry and Fisheries, Chiba, Japan
Email: kusadai@frontier.hokudai.ac.jp

TADAO YAMAMOTO
Hokkaido University, Hokkaido, Japan

TAKASHI INOUE
Hokkaido University, Hokkaido, Japan

TETUAKI NAGASAWA
Emeritus Professor, Hokkaido University, Hokkaido, Japan

Received 24 October 2013 Accepted 1 March 2014 (*Corresponding author)

Abstract The study attempts to clarify the functions of oxbow lakes in rural irrigation systems. The status of oxbow lakes was briefly investigated through interviews with town officials and land improvement agencies. It is clear that even though canals have been constructed in the area, oxbow lakes in the Ishikari River basin are utilized as primary and auxiliary irrigation resources and as reservoirs for circulating irrigation systems. In the Urausu region, 14% of the irrigation water resource comes from oxbow lakes. The percentage of drainage into the oxbow lakes is 72.0% during the puddling period and 64.6% during the normal period. The percentage of water recycled through the oxbow lakes is 76.3% during the puddling period and 66.4% during the normal period. Furthermore, all water used in circulating irrigation is obtained from the oxbow lake in the region around Karisatonuma. This reduces the amount of water taken from the river. This suggests that rural resources, such as oxbow lakes, can continue to be used as a component of regional irrigation systems. This information may be beneficial as a reference for cost-effective development of rural irrigation systems in developing countries.

Keywords Oxbow Lake, regional resource, circulating irrigation, Ishikari River, conservation of water environment

INTRODUCTION

As global water demand increases, the development of irrigation systems, especially in developing countries, becomes increasingly important. This is also important for reducing poverty. Although international support is evident in many developing countries, in some cases, this support is insufficient to develop adequate irrigation infrastructure. Therefore, it may be beneficial to involve regional resources to facilitate the development of irrigation systems in areas of poverty.

To date, several studies have examined regional water usage. Yenigun et al. (2010) have studied and evaluated Turkey's irrigation systems, and Liyantono et al. (2012) studied the operational status of conjunctive water use in Indonesia. However, local resources, such as oxbow lakes, are not commonly incorporated in localized irrigation and drainage systems. Similar to lakes or ponds, which are typical water resources in mountainous areas, oxbow lakes are typical water resources in a river basin. Oxbow lakes are remnants of meandering flood plain rivers that have been cut off and physically isolated from their respective main river channels (Cullum et al., 2006). In Kenya, small-scale irrigation farming is being undertaken around a considerable number of oxbow lakes previously surrounded by seasonal wetlands (Mutero, 2002). In addition, oxbow lakes

are used for small-scale aquaculture in Bangladesh (Thapa, 2004). Therefore, oxbow lakes can be a useful water resource for primary industries in developing countries. McQueen et al. (1982) and the United States Department of Agriculture (1999) studied the relationship between water quality of oxbow lakes and agriculture in the Mississippi river basin. Yamamoto et al. (2004) conducted a similar study of the Ishikari River basin. However, studies of oxbow lakes as sources of water for irrigation have not been conducted. Studying effective use of rural water resources is important for the future development of a particular region and can also be used as a reference for other developing areas.

In this study, we target the Ishikari River basin in Hokkaido, Japan. This agricultural region has many oxbow lakes which function as rural water resources. By studying this region, we can obtain a complete view of oxbow lakes as localized rural sources of water. Furthermore, we aim to demonstrate the usefulness of utilizing existing rural water resources in irrigation development.

Overview of Oxbow Lakes in Ishikari River Basin

According to a study of oxbow lakes in the Ishikari River basin (Kusa et al. 2001), oxbow lakes have many features. Around the Ishikari River, there are many oxbow lakes that have been formed naturally **(**Fig. 1**)** and artificially.

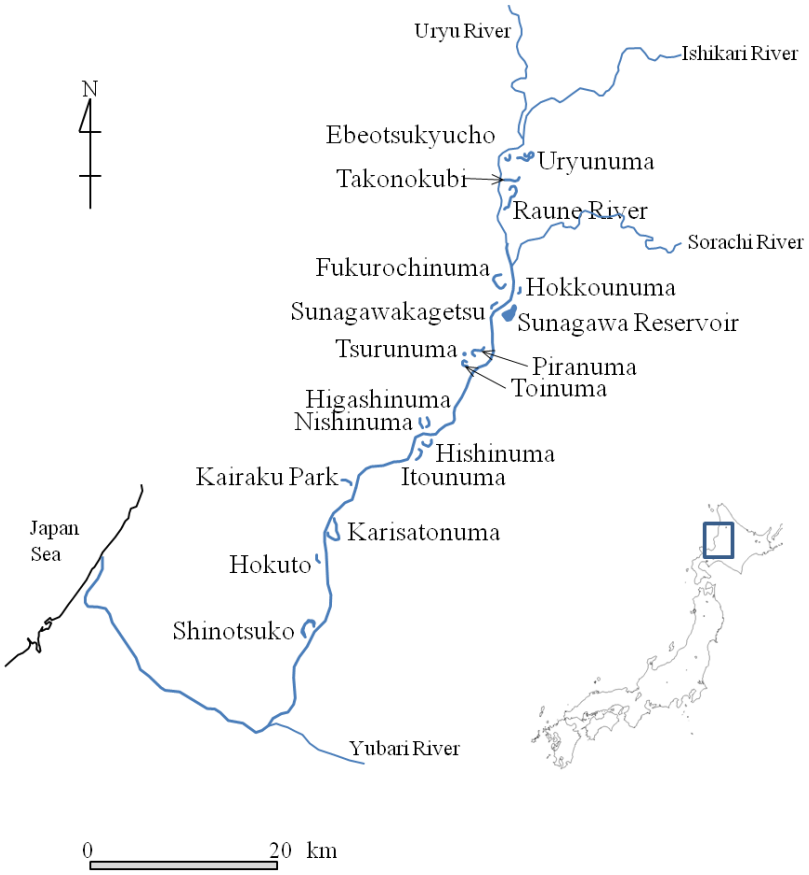

Fig. 1 Natural Oxbow Lakes in the Ishikari River basin

A common feature of oxbow lakes is that they have both sluice gates and agricultural drainage inflow from the surrounding areas. Generally, oxbow lakes are used for agriculture, parks, and flood control. From an agricultural perspective, oxbow lakes have sufficient water volume for irrigation because they originate close to large river systems. The land around oxbow lakes is often used for farming because the soil is well drained. Lands around oxbow lakes are also frequently used as parklands because of their unique biotope functions. In addition, oxbow lakes are also used

as temporary reservoirs during flooding to reduce pump overload. In the Ishikari River basin, oxbow lakes are primarily used for agricultural purposes (Table 1).

Table 1 Oxbow Lakes in the Ishikari River basin

No.	Name	Area (km^2)	Using situation				Sluice Gate
			Agriculture	Park	Flood Control	Others	
1	Tsuikari	-	○	-	-	A part of river	-
2	Old Ishikari River	0.359	○	-	○	-	○
3	Shimotappu	0.027	○	-	-	-	○
4	Kitsunemori	0.047	○	○	-	-	○
5	Karisatonuma	0.476	○	○	-	-	○
6	Kairaku Park	0.087	-	○	○	A part of river	○
7	Sunagawa Reservoir	0.773	-	○	○	-	○
8	Raune River	0.365	○	○	○	-	○
9	Takonokubi	-	○	-	-	A part of river	○
10	Shinotsuko	0.329	○	○	-	-	-
11	Itounuma	0.133	○	○	-	-	○
12	Hishinuma	0.100	○	-	-	-	○
13	Nishinuma	0.114	○	-	-	-	○
14	Higashinuma	0.112	○	-	-	-	○
15	Tsukinuma	0.018	○	-	-	-	-
16	Utsuginuma	0.013	○	-	-	-	-
17	Shin-numa	0.199	○	-	-	-	○
18	Urausunuma	0.075	-	-	-	-	○
19	Mikazukinuma	0.050	○	-	-	A part of river	○
20	Toinuma	0.145	○	-	○	-	○
21	Piranuma	0.105	○	-	-	-	○
22	Hokkounuma	0.065	-	○	-	-	-
23	Fukurochinuma	0.389	○	-	○	-	○
24	Uryunuma	0.044	○	-	-	-	○
25	Tambanonuma	0.014	○	○	-	-	○
26	Tsurutanonuma	0.077	-	○	-	-	-
27	Tsurunuma	0.008	-	○	-	-	-
28	Sunagawakagetsu	0.053	-	-	○	-	○
29	Ebeotsukyucho	0.077	○	-	-	-	○
Total			21	11	7		

Source: Kusa et al. 2001

Based on this, we focus on the actual various agricultural uses of oxbow lakes using concrete examples, such as a primary water resource, an auxiliary resource, and an intermediate reservoir for irrigation from the main canal.

METHODOLOGY

In this study, we focus on several oxbow lakes in the Ishikari River basin, Nishinuma and Higashinuma, which are used for irrigation in and around the town of Urausu. We also focus on Karisatonuma, which is used for irrigation between the town of Tsukigata and Iwamizawa city. To understand the movement of irrigation waters in these areas, we investigated ownership documents and interviewed representatives from local governments and land improvement agencies. We examined areas around oxbow lakes to assess beneficiary areas, the volume of irrigation water during normal and puddling periods, and drainage destinations. Based on this, it is possible to determine the irrigation water flow from the oxbow lakes and the drainage water flow into the oxbow lakes. By comparing these flows with the entire flow of water use in the region, we estimated the function of oxbow lakes in the regional circulating irrigation.

RESULTS AND DISCUSSION

Function of An Oxbow Lake as Auxiliary Water Resource for Circulating Irrigation

To facilitate our investigation of an oxbow lake as an auxiliary water source for irrigation, we examined the Urausu region. The town of Urausu is located on the Ishikari River in a region where many oxbow lakes have been formed by flooding. In this area, irrigation water is taken from the Ishikari River through main canals that were constructed in 1966. Before the construction of the canals, recycled drainage water by the oxbow lakes was used to supply irrigation water. After construction of the canals, circulating irrigation from the oxbow lakes has also been used.

Water use rights, specific to the use of irrigation water from oxbow lakes, were in place from the 1940s to the 1960s. The rights were extinguished after construction of the main canal in 1966. However, the demand for auxiliary water increased, and consequently, the rights were re-established in the 1983 and remain in effect. Since the re-establishment of the water rights, water from oxbow lakes has been used to satisfy various needs. Today, 14% of the irrigation water resource in the Urausu region comes from oxbow lakes and 24% comes from tributaries. This indicates that small rivers, as well as oxbow lakes, were recognized as local resources when the main canal system was constructed (Table 2).

Table 2 Irrigation water resources in the Urausu region

Water resource	Flow (m^3/s)	Percent (%)
Oxbow Lake	0.59	14
River	1.00	24
Irrigation Canal	2.59	62
Total	4.18	100

In addition to use as a source of irrigation water, oxbow lakes are used for other purposes.The pattern of total water usage in the Urausu region is shown in Fig. 2, which indicates extensive water circulation.

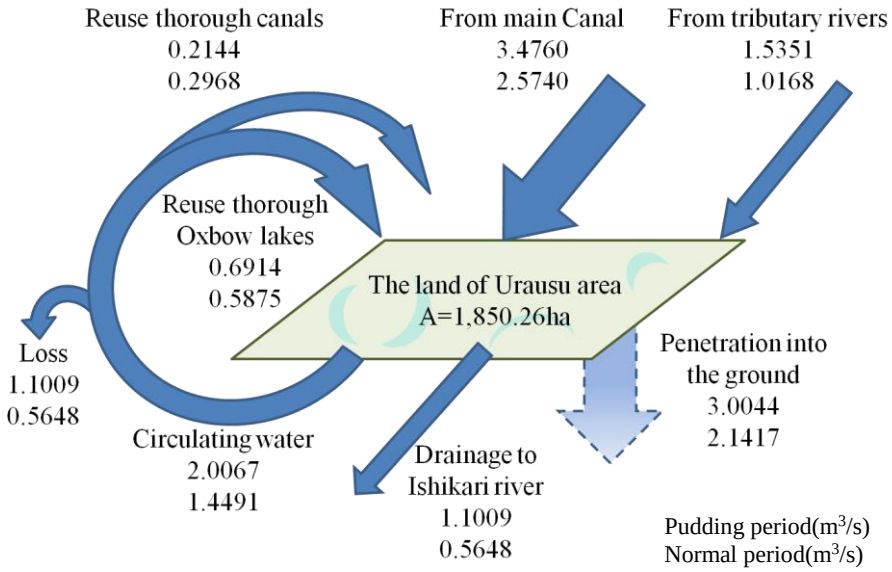

Fig. 2 Total water usage in the Urausu region

The circulation and use of agricultural water is a significant feature of the Urausu region. In the region, more water drains into the oxbow lakes than into to the Ishikari River. Drainage (X) can be expressed as in Eq. (1)

$$X(\%) = \frac{\text{Circulation water } (m^3/\text{s})}{\text{Circulation water } (m^3/\text{s}) + \text{Drainage Ishikari river } (m^3/\text{s})} \times 100 \quad (1)$$

In this calculation, X is 64.6% in the puddling period and 72.0% in the normal period. Some water is lost in the reuse process; however, the water that is recycled (Y) through the oxbow lakes can be expressed as in Eq. (2)

$$Y(\%) = \frac{\text{Reuse through oxblow lakes } (m^3/\text{s})}{\text{Reuse through oxblow lakes } (m^3/\text{s}) + \text{Reuse through canals } (m^3/\text{s})} \times 100 \quad (2)$$

Y is 76.3% in the puddling period and 66.4% in the normal period. A comparison with the actual flow rate is shown in Fig. 2. During the puddling period, water reuse from oxbow lakes increases to 0.6914 m^3/s from 0.5875 m^3/s in the normal period. Water reuse from canals decreases from 0.2968 m^3/s during the puddling period to 0.2144 m^3/s during the normal period. This indicates that an oxbow lake is more important during the puddling period because the storage function of an oxbow lake is more beneficial when water reuse increases. Therefore, it is reasonable to conclude that oxbow lakes have been used as a base for agricultural water circulation for this reason. On the other hand, canals do not contribute to water reuse significantly. Oxbow lakes in the Urausu region can collect waste water easily because they are located downstream from branches of the Ishikari River. Moreover, as oxbow lakes function as temporary storage repositories, it seems to be more practical to pump water from oxbow lakes than from canals.

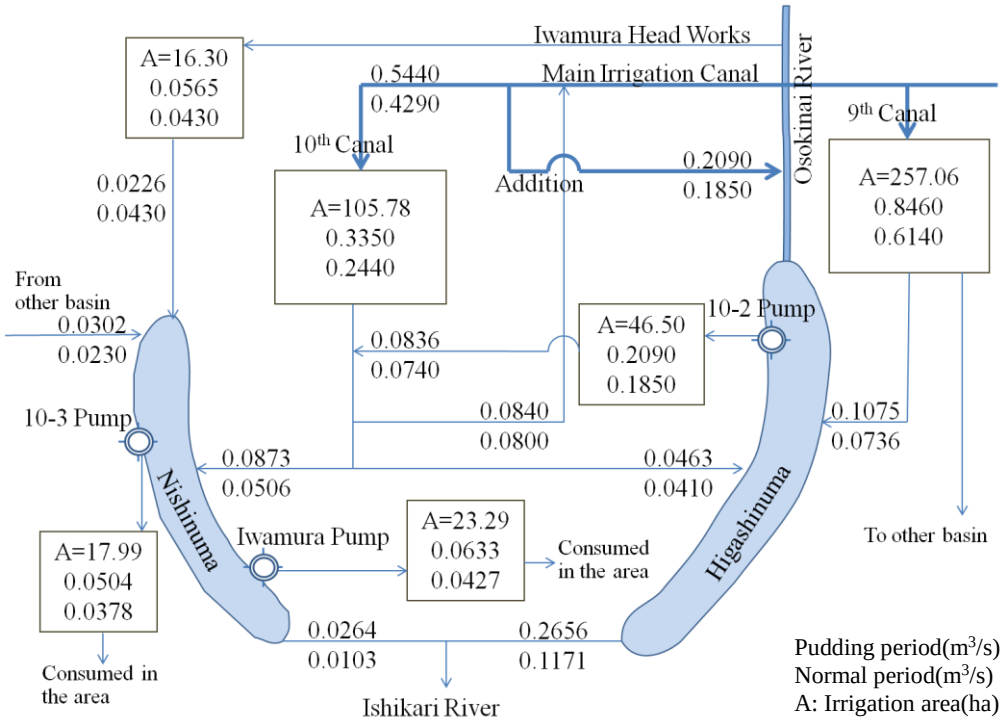

Fig. 3 Pattern diagram of water movement in Sangen-ya

In particular, in Sangen-ya, which is enclosed by oxbow lakes, irrigation water supply is more dependent on oxbow lakes than other areas. Fig. 3 shows a pattern diagram of water movement in Sangen-ya, which illustrates the complexity of water movement. Moreover, water flow into Nishinuma has been restricted such that it only receives agricultural drainage. Nishinuma also supplies irrigation water to land around the lake. Therefore, it is reasonable to conclude that only drainage water is used in the Nishinuma circulating irrigation system. Because Nishinuma is located at the end of the Urausu canal irrigation system, sometimes, for example during droughts,

water from the canal system does not reach the lake. When such conditions occur, farmers use water from Nishinuma. Therefore, it is evident that oxbow lakes water resources are important to stabilize farm management.

The plan associated with the water rights for Higashinuma stipulated that irrigation water should be taken from the main canal rather than from the lake. However, there are restrictions on the land enclosed by Higashinuma, and canals connecting the lake to farmland could not be built. In actual practice, irrigation water goes into Higashinuma and farmers pump water from the oxbow lake. As a result, we can say that, in this situation, the oxbow lake functions as a reservoir in the irrigation system.

Function of An Oxbow Lake as Main Water Resource for Circulating Irrigation

In this section, we describe a case in which an oxbow lake is used as the main resource for circulating irrigation. Karisatonuma is an oxbow lake that is located between the town of Tsukigata and Iwamizawa city. The land enclosed by the oxbow lake and the Ishikari River belongs to Tsukigata, even though the town is situated primarily on the west side of the river. Tsukigata's current location is the result of work conducted in 1940, which changed the course of the river. A land improvement project was carried out in 1981 and 1982. The pumps that are used currently were installed at that time. Moreover, even before the land improvement project, water from the oxbow lake was used for circulating irrigation. Fig. 4 shows the location of Karisatonuma. The most significant difference between this region and the Urausu region is that all irrigation water is taken from Karisatonuma.

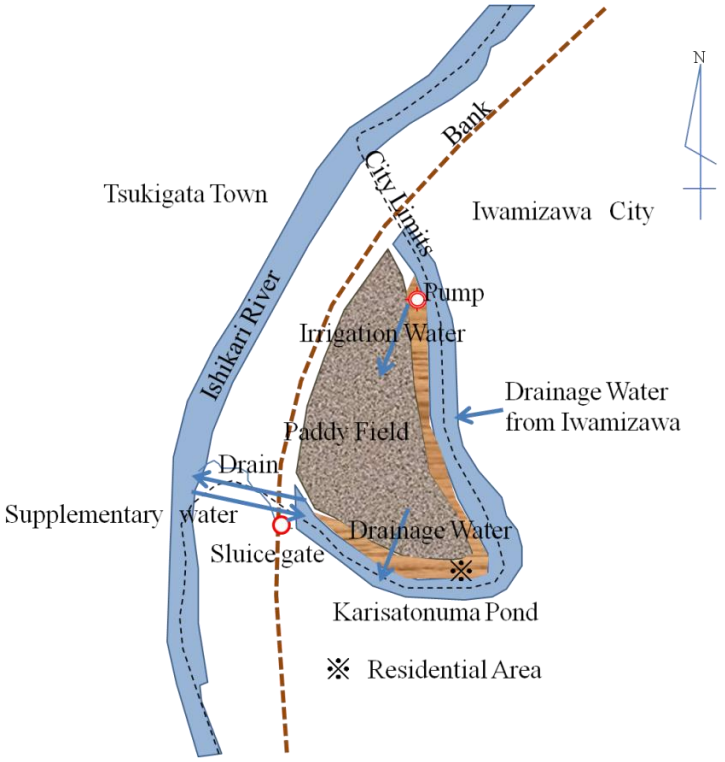

Fig. 4 Karisatonuma

There is no official plan to supply irrigation water to the oxbow lake from the river. However, when water levels are exceptionally low, water is resupplied through the sluice gate. Under such circumstances, Karisatonuma water is only supplied by drainage from each side of the oxbow lake. Incidentally, the water rights allow water to be pumped directly from Karisatonuma, as a part of the Ishikari River because the oxbow lake had been really part of the river until 1940. As indicated by

the above, water from the oxbow lake is used as circulating irrigation for the land around Karisatonuma, which reduces the amount of water taken from the river.

According to the local government, this water system functions satisfactorily and allows farmers access to water for various uses, such as deep ponding irrigation to protect crops from damage during cool summer weather.

CONCLUSION

In this study, from actual use of examples and data, it is evident that oxbow lakes in the Ishikari River basin have many functions. In particular, we can conclude the following:

1. Oxbow lakes function as primary and auxiliary resources for rural irrigation, and as a reservoir for circulating irrigation. In addition, each of the functions is dependent on geography, the existing irrigation systems, or other circumstances specific to each particular oxbow lake.
2. As the storage function of an oxbow lake is very useful when water reuse increases, the function of an oxbow lake changes relative to changes in the water balance in the area.

Although beyond the scope of this study, in 1956, a large land improvement project financed by the World Bank was undertaken in a different section of the Ishikari River basin. Major canals were constructed at that time. However, many oxbow lakes, which were used as irrigation resources before the land improvement project, still remain. Furthermore, in the Urausu region, a new dam was constructed in 2010. Consequently, irrigation in this region will stabilize and become less dependent on oxbow lakes. However, the change in water use will result in a change of the role of oxbow lakes and may affect the biotope and other environmental elements. Therefore, attention should be paid to the possibility that these changes may affect the ecosystem or the water quality.

An understanding of how oxbow lakes function may be a useful reference for rural development, especially at a community level in developing countries. Oxbow lakes have characteristics that can be leveraged to reduce both infrastructure costs and water use. Although economic conditions and infrastructure development differs among countries, many developing countries do not have sufficient financial resources to commit to effective but expensive infrastructure projects. Moreover, there are insufficient water supplies in some regions. In these cases, using rural resources like oxbow lakes seems more reasonable and promising than undertaking expensive infrastructure projects.

REFERENCES

Cullum, R.F., Knight, S.S., Cooper, C.M. and Smith, S. 2006. Combined effects of best management practices on water quality in oxbow lakes from agricultural watersheds. Soil and Tillage Research, 90(1-2), 212-221.

Kusa, D., Yamamoto, T., Nagasawa, T. and Inoue, T. 2001. Evaluation of oxbow lake for rural resource from its flood control function in Ishikari River basin. Journal of Rural Planning Association, 20, 67-72.

Lee, J.1999. Agricultural research service of United States department of agriculture, science and education administration. Delta MSEA Benefits Local Ecology, Agricultural Research Magazine, 47(3), 20-21.

Liyantono, Kato, T., Kuroda, H. and Yoshida, K. 2012. GIS analysis of conjunctive water resource use in Nganjuk district, east Java, Indonesia. Paddy and Water Environment, 11(1-4), 193-205.

McQueen, A.D., Shulstad, R.N. and Osborn, C.T. 1982. Controlling agricultural soil loss in Arkansas' North Lake Chicot watershed: A cost analysis. Journal of Soil and Water Conservation, 37(3), 182-185.

Mutero, C.M. 2002. Health impact assessment of increased irrigation in the Tana River Basin, Kenya. The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa, 211-29.

Thapa, G. 2004. Rural poverty reduction strategy for South Asia. Australian South Asia Research Centre Working Paper, 2004-06, 1-26.

Yamamoto, T., Kambe, T., Nagasawa, T., and Inoue, T. 2004. Water environment of oxbow lake and landuse of its watershed in the Ishikari River basin. Journal of Rural Planning Association, 23, 67-72.

Yenigun, K. and Aydogdu, M.H. 2010. Evaluation of irrigation and drainage systems of (Southeastern Anatolia Project) GAP, the Turkey's largest integrated water resource development project. Scientific Research and Essays, 5(21), 3237-3253.