An inquiry into institutional drought adaptation and sustainability: Some implications from the case of the Sanuki plain

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1. Introduction

This paper investigates the process of institutional adaptation to drought in the case of the severe 1994 drought in the Sanuki plain (Kagawa Prefecture) and examines the effectiveness and limits of Ostrom's analytical framework in light of this case. The Sanuki plain is one of the driest regions in Japan. Having suffered from serious water shortages frequently, farmers in the Sanuki Plain have developed an extensive pond irrigation system in conjunction with local institutions to achieve a stable water supply. This pond irrigation system, which is mostly connected to the Kagawa Canal and forms a complex water distribution network across the Sanuki plain, played an important role in adaption to the severe drought of 1994.

The Sanuki Plain is located to the northeastern part of Shikoku island in Japan (Figure 1). In the Sanuki Plain, it has been difficult to irrigate land in a stable manner due to geological, geographical, and climatic conditions, and people have long suffered damage caused by frequently occurring droughts. In attempts to mitigate such problems, systems of irrigation centering on ponds have been extensively developed since the *jori* system of land readjustment in the ancient period (*kodai*), and unique traditional practices of agricultural irrigation have been devised to respond to the frequent droughts (Nagamachi 1991, Kagawa Canal Land Improvement District 1998). These traditional practices include, *bansui*, a practice for efficient use of reservoir water based on efforts to prolong water supply from reservoirs and distribute water according to plans, as well as water-saving irrigation techniques like *kiriotoshi* and *hashiri-mizu* intended to increase water use efficiency in individual crop fields[1].

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[1] Other traditional practices involving agricultural irrigation in the Sanuki Plain include what is called *gisei-den*, a measure to prevent the crops in the entire crop fields in pond appropriators from withering and dying due to water shortages by completely stopping water distribution to some fields and intentionally letting the crops in these fields wither and die. As an adaptive measure against droughts,

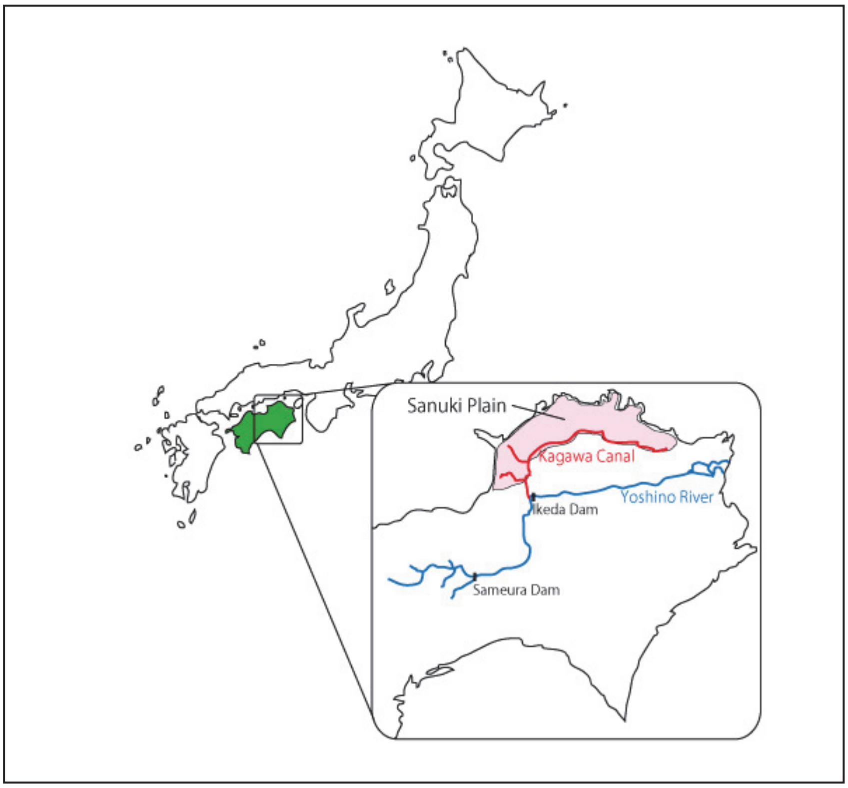

Figure 1: Location of the Sanuki Plain and Kagawa canal in Japan

As water shortages had frequently occurred in the Sanuki Plain, the Kagawa Canal project was planned and implemented in order to fundamentally improve water supply as part of a comprehensive development project for the Yoshino River in the Sanuki Plain (the positional relationship is illustrated in Figure 1). The project aimed at drawing to Kagawa Prefecture 247 million tons of water through the Ikeda Dam, which is about 29% of the annual capacity developed, 863 million tons per year, of the Sameura Dam which was constructed for the Yoshino River running through Tokushima Prefecture. The construction of the Kagawa Canal began in 1968, and the entire canal was opened in 1978. The amount of water flowing in the Kagawa Canal is 105 million tons per year for agricultural use, 122.1 million tons per year for drinking water, and 20 million tons per year for industrial use. The area of agricultural land benefiting from water from the canal is 30,700 ha (rice paddies: 25,100 ha; treed farmland: 5,600 ha). The drinking water is supplied to 8 cities and 5 towns in Kagawa Prefecture (940,000 residents). The seaside industrial zone encompassing Sakaide and Marugame in the Chusan region benefits from water from the canal. The Kagawa Canal is divided into shared sections and sections for

gisei-den is an interesting subject in itself, but it is not analyzed in this paper.

agricultural use, and the former and latter are maintained and managed by the Water Resources Development Public Corporation and the Kagawa Canal Land Improvement District (hereafter, KCLID), respectively. The Kagawa Canal is the main artery of the Sanuki region, and 56% of water demanded by 5 cities and 19 towns in Kagawa Prefecture comes from the canal (Tomiyama 1999, p. 11). As we see later, the Kagawa Canal has not only drastically increased the amount of irrigation water, water for industrial purposes, and drinking water available, but has also enabled interbasin water transfer through the canal as it was constructed so that it would run eastward through the major rivers in Kagawa Prefecture (e.g. the Kanakura River, Doki River, Aya River, Koto River, and Shin River). With the irrigation adjustment function based on the main line of the Kagawa Canal, interbasin water transfer was conducted during the extreme drought of 1994 in the spirit of sharing limited resources.

2. An extreme drought occurred in the Sanuki Plain in 1994

In 1994, an extreme drought hit the Sanuki Plain. Not only the ponds all around the Sanuki plain but the Sameura Dam (water storage of Kagawa canal) had severely depleted due to the drought. It is reported that the precipitation from June to August in the western part of the Sanuki plain had dropped by 68 percent compared to the same period in an annual year. In the same period, precipitations in the upper area of Sameura Dam was about 36.5 lower than in an average year. Both the ponds in the Sanuki plain and the water storage on Sameura Dam had rapidly depleted. From June 29, the Kagawa Canal was imposed restrictions by 30% on water intake from Sameura Dam on Yoshino River as the rate of water storage of Sameura Dam fell below 50%. After a couple of days without rain, it was decided on July 4 to raise the restriction rate to 60% when the storage rate of Sameura Dam fell below 30% in the Association of water users of Yoshino River[2]. On the same day, a special task force in Kagawa prefecture to address a potential water shortage asked the KCLID for a cooperation to set higher restriction rates on agricultural water intake. It was a hard request for the members of KCLID since the restriction rate was 30% and the water storage rates of their pond reservoirs was already falling below 70%, 15% lower than that in an average year. Through a deliberate consideration, the Water Distribution Committee

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[2] The members of the Association of water users of Yoshino River include the Shikoku Island Regional Construction Bureau, Chugoku and Shikoku Island Regional Agricultural Administration Office, Shikoku Island Regional Bureaus of International Trade and Industry, Water Resources Development Public Corporation, Kagawa prefecture, Tokushima prefecture, Ehime prefecture and Kochi prefecture.

in the KCLID decided to accept the request to set higher restriction rate on agricultural water to help people in cities who would suffer from water shortage. At the same time, the Water Distribution Committee also promised to the members of KCLID to supply agricultural water from the Kagawa Canal preferentially to those who suffer from the loss of agricultural crops. On the second stage of restriction started from July 8, the restriction rate on domestic water was set to 51% while that on agricultural water was set to 65%.

On July 12, the Association of water users of Yoshino River decided that from the date when the storage rate of Sameura Dam would fall to 15%, the restriction rate of the Kagawa Canal would raise to 75% (the third stage restriction). It was the first case to proceed to the third stage restriction since the Kagawa Canal was constructed and started to operate in 1978. Like what happened on July 4, the special task force in Kagawa prefecture asked again KCLID to set higher restriction rate on agricultural water on July 12. It touched off raucous debates in the KCLID since the storage rates of local ponds fell below 60% and some members of the KCLID already faced severe situations. However, KCLID had no choice but to accept the request since the situation on domestic water was critical and it was anticipated that setting up the restriction rate as 75% would upset people's life living in the cities in Kagawa prefecture. Based on this agreements, the restriction rates were raised to 56% on domestic use and 80% on agricultural use. Around this period, farmers in the Sanuki Plain began to implement traditional practices of agricultural irrigation such as *bansui*. And on July 24, the storage rate of Sameura Dam finally depleted and it became impossible to intake water from there to the Kagawa Canal. From July 24 to 25, the Kagawa Canal could not supply water at all. For the purpose of helping those people using domestic water in Kagawa prefecture, water for power generation that still remained on the bottom of the Sameura Dam was transferred to the domestic water sector of the Kagawa Canal while KCLID could not still intake water from the Kagawa Canal. It was anticipated that this situation would persist for some time, and fortunately a typhoon approached to Shikoku island, bringing the Sameura Dam precipitations. This enabled KCLID to intake water from the Kagawa Canal temporarily (from July 25 to 28) up to 70% as it was planned in average year. It was good fortune for people in Kagawa prefecture, however, the pattern of precipitation was so unstable that the drought period continued until November 14.

As showed in Table 1, while the intake of agricultural water was restricted to 59.6%, domestic water sector could use 83.3% as it was planned in an average year.

Table 1: The rate of water intake of the Kagawa Canal from Sameura Dam in 1994 (from June 11 to September 10)

	Water intake as planned (A) (×1,000m³)	Actual water intake (B) (×1,000m³)	Rates of water intake (B/A)
Agricultural use	76,564	45,612	59.6%
Domestic use	32,676	27,216	83.3%
Industrial use	6,620	3,033	45.8%
Total	115,860	75,861	65.5%

Souce: Kagawa Canal Land Improvement District (1998)

Table 2: Adaptations to the extreme drought in the Sanuki Plain in 1994

	Content	Purpose	Stakeholders
(1)	Revived traditional practices of agriculatural irrigation	To avoid the loss of agricultural crops	Members of KCLID (and/or appropriators of local ponds), farmers
(2)	Temporal water transfer within agricultural sector (Preferential water distribution to drought-prone areas)	To avoid the loss of agricultural crops among the members of KCLID	KCLID, members of KCLID, farmers
(3)	Temporal water transfer from agricultural sector to domestic sector	To mitigate the effect of restricting the use of domestic water	The special task force in Kagawa prefecture to address a potential water shortage, water works department in Kagawa prefecture, KCLID, Members of KCLID (and/or appropriators of local ponds), farmers, citizens

Source: by author

Table 2 denotes the countermeasures against the extreme drought that was implemented in the Sanuki plain in 1994. Firstly, some of the declining usage of traditional practices of agricultural irrigation revived in the Sanuki plain when the average rates of ponds' water storage had decreased less than 50 percent on mid-July in 1994 (Kagawa Canal Land Improvement District, 1998). These traditional practices include water-saving irrigation techniques like *kiriotoshi* and *hashiri-mizu* intended to increase water use efficiency in individual crop fields. Other traditional practices include, for example, 'ikemori', 'mizuhai', 'matamori', 'mizuhiki', 'kuwakatagi', and 'hashiri' that is aimed to distribute ponds' scarce water strictly as it has been planned. These traditional practices of agricultural irrigation can be said to constitute a system for intrabasin water transfer. It is conducted by the parent pond (large reservoir) appropriators through the process of reconsciling interests between the constituent members (child pond appropriators) based on criteria (e.g., the water level of the reservoir) that have been historically agreed upon by members of the area benefiting from the parent pond.

Secondly, KCLID conducted temporal water transfer among the members of KCLID to avoid the loss of agricultural crops by preferentially distributing water to drought-prone areas in the Sanuki Plain[3]. Since the Kagawa Canal became operational in 1978, it has been possible to transfer water between basins, which had been physically impossible up to that point, by adjusting the amount of water flowing from the main line of the Kagawa Canal through secondary canal intakes while utilizing major reservoirs in the Sanuki Plain as regulating reservoirs (Nagamachi 2003). It was conducted under mediation of the KCLID, which manages the Kagawa Canal: through the main line of the canal the KCLID distributes water to 79 land improvement districts and irrigation associations in the prefecture in accordance with the amounts agreed upon by them. During the extreme drought of 1994, an adaptive measure was taken, with both intrabasin water transfer based on traditional practices of agricultural irrigation and interbasin water transfer through the main line of the Kagawa Canal being conducted. Interbasin and intrabasin water transfer conducted in the Sanuki Plain in 1994 are an important institutional adaptive measure against drought[4].

Distribution of water for agriculture in the Sanuki Plain is characterized by the fact that the irrigation system of the main line of the Kagawa Canal and the traditional pond

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[3] In terms of government administration, water transfer is regarded as a measure in which entities facing serious droughts obtain, on a temporary basis, the amount of water needed to eliminate shortages from entities with sufficient water, within the limits of the amount of water guaranteed to the latter entities under their water rights. The River Act defines water transfer as a special irrigation measure in times of drought, and Article 53, Paragraph 2 of the law (amended) states the possibility of simplifying procedures such as meetings with relevant central government agencies and consultations with relevant local governments. In other words, in government administration, water transfer is a temporary trade of irrigation water that is conducted within the framework of the water use rights granted by the river administrator. In contrast, water transfer in the Sanuki Plain goes beyond such a framework and functions as a comprehensive adjustment measure against drought which combines water rights granted by the authorities and water rights based on traditional practices.

[4] Adaptive measures against external changes include investment in regional capital assets such as man-made capital and human capital. Adaptation by renewing the mechanism for utilizing such capital assets is particularly called institutional adaptation. In conservation ecology, the concept of adaptive management refers to flexible renewal of resource management methods, which is attained while learning management results, with an assumption of scientific uncertainties regarding ecological mechanisms and behavior. Although adaptive management is similar to institutional adaptation in some respects, the connection and differences between them are not considered in this paper, but will be the subject of a future paper.

(reservoir-based) irrigation system are managed in an integrated manner. Water for agriculture that branches off the Kagawa Canal does not go directly to the destination crop fields, but instead goes first to reservoirs in the prefecture and then to the destination crop fields through the existing traditional pond irrigation system (Nagamachi 2003, p. 118). More specifically, there are two routes for water distributed through the main line of the Kagawa Canal: (A) water from the main line of the Kagawa Canal goes to a large pond called a parent pond and then to a reservoir called a child pond, which is owned by pond appropriators; (B) water from the main line of the Kagawa Canal goes directly to a reservoir (child pond) owned by pond appropriators.

Table 3: Routes for Water Distributed to Destination Crop Fields

	Route for water distributed to crop fields	Interbasin water transfer	Intrabasin water transfer
Route A	Main line of the Kagawa Canal → parent pond → child pond → crop fields	Yes	Yes
Route B	Main line of the Kagawa Canal → child pond → crop fields	Yes	No
Route C	Parent pond → child pond → crop fields	No	Yes
Route D	Child pond → crop fields	No	No

Souce: by author

3. Evaluating the sustainability of the institutional drought adaptation implemented in the Sanuki Plain in 1994

3.1. Ostrom's analytical framework

In Ostrom's analytical framework, institutional system of CPRs is supposed to be modified and updated by the appropriators of CPRs themselves and the main interests are focused on how situations of CPRs is affected by the dynamic process of institutional change, and on what the institutional conditions are to avoid the depletion of CPRs. Ostrom (1990) offers a hypothetical answer to the latter question, summarized as the design principles. The design principles make it possible to evaluate institutional systems from the perspective of sustainability of CPRs.

Ostrom's theory of commons aims at clarifying the institutional conditions for managing CPRs sustainably and finding out the mechanisms of institutional change that is brought about by the appropriators of CPRs. Having surveyed the results of field researches, E. Ostrom has successfully extract the conditions of sustainable management of CPRs, which is called as the "design principles" as follows (Ostrom, 1990, 2005; 井上真, 2009).

(DP1) Clearly defined boundaries
(DP2) Congruence between appropriation and provision rules and local conditions
(DP3) Collective-choice arrangements
(DP4) Monitoring
(DP5) Graduated sanctions
(DP6) Conflict-resolution mechanisms
(DP7) Minimal recognition of rights to organize
(DP8) Nested enterprises

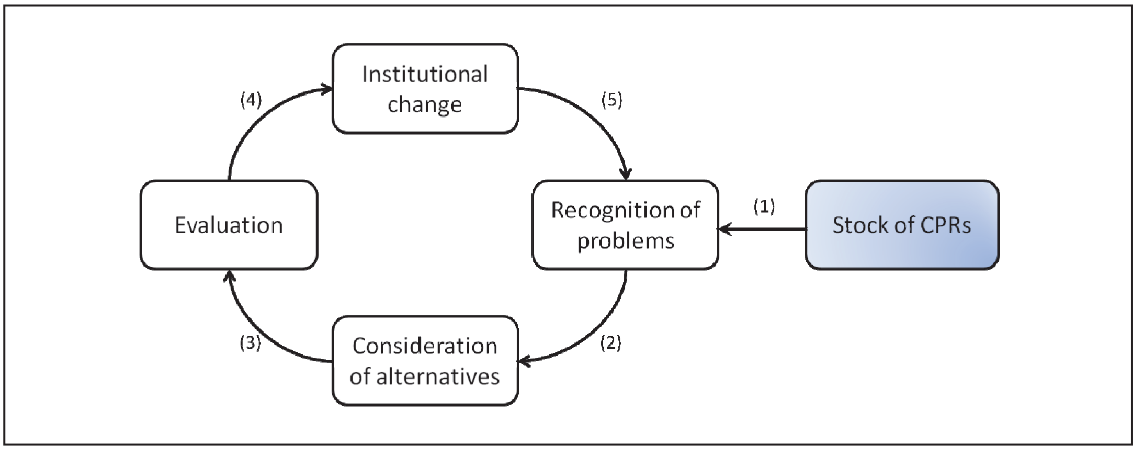

Figure 2: An illustration of the Ostrom's analytical framework

Figure 2 exhibits the Ostrom's analytical framework of commons. Arrow (1), (2), (3), (4) and (5) denotes the evolutionary process of institutional change. CPRs are managed under the current institutional system and the stock level of CPRs is monitored. If the resource flow is withdrawn more extensively for a long period, the stock level of CPRs will decrease toward depletion. When the trend of depletion of CPRs is clearly recognized, appropriators will try to identify the cause of mismanagement of CPRs and modify or renew the institution of them autonomously. That is, it is assumed that the alternative to current institution will be offered by the appropriators through their discussions. Weighing the expected benefits and costs that will occur under the proposed alternatives (arrow (3)), an institutional alternative will be adopted if the expected benefits outweigh the expected costs, and built into the current institutional system (arrow (4)). If the renewed institutional system does not appropriately prevent the depletion of the stock level of CPRs, appropriators will repeat this process (arrow (5)). This is the analytical framework that Ostrom has adopted to explain the evolutionary process of institutional change of CPRs brought about by the appropriators themselves. The design principle is related to the part between the evolutionary process of institutional change and the stock level of CPRs and offers criteria to evaluate the relationship between them.

3.1.1. Clearly defined boundaries (DP1)

The boundary of ponds in the Sanuki plain and their appropriators are clearly defined. Although the range of water source and the member of appropriators of ponds may have changed historically, however, the right to use pond's water flow has been clearly defined. Similarly, the same holds true for Kagawa canal.

3.1.2. Collective-choice arrangements (DP3), Conflict-resolution mechanism and Minimal recognition of rights to organize (DP7)

The water allocation policy of the Kagawa canal on the period of the extreme drought in 1994 was supposed to be determined by the Water Allocation Control Board whose members are twelve directors, and 150 representatives of the KCLID. The representatives are elected by the whole member of the KCLID (about 59 thousand people) from 41 election districts. Fifty directors altogether are also chosen from 36 election districts and the twelve directors are assigned to the Water Allocation Control Board. This means that, firstly, it is socially authorized that the members of KCLID can autonomously use Kagawa canal as a source of agricultural water; secondly, the members of KCLID has a chance to express their opinions through the representatives all over the Sanuki Plain. In addition to that, the KCLID was acting as a troubleshooter in the Sanuki Plain in 1994. KCLID tried to avoid concentrating the loss of agricultural crops in one place by conducting the interbasin water transfer, which contributed to alleviating conflicts among the members of KCLID.

The same holds true for the use of ponds in the Sanuki plain. For example, on *Manno* -ike Land Improvement District, sixteen directors who determine the basic policy how to allocate the pond's water and 113 representatives who deliberate the policy are elected. Such kind of a decision making mechanism can be found in other land improvement districts in the Sanuki plain. Some traditional practices in the Sanuki Plain such as *ideagari* worked as a conflict-resolution mechanism. *Ideagari* is a measure to lessen the inequality in irrigation between upstream areas and downstream areas in pond appropriators by distributing water first to users located around the end of the stream, then to users located immediately above them, and so on. It is fair to say that this unique practice promoted a fair use of reservoir water in the period of extreme drought.

Table 4: The voting districts and number of seats in KCLID

		Irrigated area	Number of seats				Irrigated area	Number of seats	
		(ha)	Directors	Represen-tatives			(ha)	Directors	Represen-tatives
1	Takamatsu	5,980	5	26	20	Ayauta	950	1	4
2	Marugame	1,730	2	9	21	Iiyama	800	1	3
3	Sakaide	1,760	2	11	22	Udatsu	170	1	1
4	Zentsuji	1,480	2	7	23	Manno	950	1	4
5	Kannonji	2,020	2	9	24	Kotohira	330	1	2
6	Hikita	300	1	2	25	Tadotsu	860	1	3
7	Shiratori	200	1	1	26	Chunan	80	1	1
8	Ouchi	500	1	3	27	Takase	1,120	2	6
9	Tsuda	140	1	1	28	Yamamoto	980	1	4
10	Okawa	140	1	1	29	Mino	540	1	3
11	Shido	420	1	3	30	Onohara	1,320	2	5
12	Samukawa	440	1	2	31	Toyonaka	790	1	5
13	Nagao	940	1	4	32	Takuma	30	1	1
14	Miki	1,290	2	7	33	Nio	360	1	2
15	Kagawa	700	1	4	34	Toyohama	570	1	2
16	Konan	590	1	3	35	Saida	180	1	2
17	Ayakami	430	1	3		Sub-total	30,500	46	150
18	Ryonan	900	1	5	36	Sanuki Plain		4	-
19	Kokubunji	510	1	1	Total		30,500	50	150

Source: Kagawa Canal Land Improvement District (1998)

3.1.3. Monitoring (DP4) and Graduated sanctions (DP5)

As we mentioned earlier, water from the Kagawa canal goes to a large pond called a parent pond and the process of distributing water from it to a reservoir called a child pond is normally governed by the traditional practices of each pond appropriator. Hence, it is not a duty of the KCLID to monitor the circumstances of water distribution on each appropriator's field. However, in the period of the extreme drought in 1994, KCLID was forced to monitor the overall process of water distribution from water gate along the main line of the Kagawa canal to the crop fields all over the Sanuki plain since it had promised to prioritize assistance to drought-prone areas.

The KCLID were monitoring the following information by conducting interviews with pond appropriators. Firstly, it strained to collect data in real-time concerning the amount of pond reservoirs and the local precipitations by sending its staffs all over the crop fields in the Sanuki plain. Secondly, it assessed what state the drought management was in each crop field. Such a drought management includes, for example, installing pumps for pumping water from ponds, digging wells, or implementing water-saving irrigations. Thirdly, it made a great effort to grasp the situation of the damages of agricultural crops in the Sanuki plain. Based on the monitoring information that Kagawa Canal Land District Improvement had collected, it requested some pond appropriators to give up taking the water from the Kagawa canal for those who were facing a crisis of crop damages.

On the level of local pond appropriators, rotational irrigation (*bansui*) was conducted all over the Sanuki Plain. This rotational irrigation system, implemented only in a drought period, calls for a strict monitoring since the foul manipulations of water gates (sometimes conducted intentionally by local farmers) are strictly prohibited. For the purpose of enforcing a strict control over the illegal water withdrawal, watchdogs were elected from the members of each pond appropriator. For example, such watchdogs are called "*kirinobori*" in the area where is irrigated by *Saburo* pond. *Kirinobori* is elected by the members of *Saburo* pond appropriators through the deliberations among them and it is reported that the number of kirinobori and their patrols were increased in 1994 about three times as many as that in other drought period (Kagawa Canal Water Management and Development Promotion Association, 2000).

3.1.4. Nested enterprises (DP8)

In the Sanuki plain, the distribution of agricultural water is normally managed not only by the KCLID on the regional level, but by each pond appropriator on the local level. Local farmers can get water from both the Kagawa canal and their ponds. In the extreme drought period in 1994, the KCLID tried to trim the conditions of water shortage and avoid the occurrence of the loss of agricultural crops all over the Sanuki plain, while each local pond appropriator was voluntarily implementing those measures such as water-saving irrigation, installation of pumps, or rotational irrigation. This kind of nested form of organizations made it possible for people in the Sanuki plain to manage agricultural water effectively in the extreme drought period in 1994.

The results of the qualitative analysis conducted in this section are summarized in Table 5. Ostrom has offered a hypothetical (empirical) criteria for judging the institutional failure of CPRs that the number of "yes" is less than three (Ostrom, 1990, pp.179-180). As shown in the Table 5, drought management institutions in 1994 can be judged as "sustainable" from the perspectives of the design principles.

Table 5: Evaluation result of the institutional adaptation to extreme drought in the Sanuki Plain

(DP1)	(DP2)	(DP3)	(DP4)	(DP5)	(DP6)	(DP7)	(DP8)
Clearly defined boundaries	Congruence between appropriation and provision rules and local conditions	Collective-choice arrangements	Monitoring	Graduated sanctions	Conflict-resolution mechanisms	Minimal recognition of rights to organize	Nested enterprises
YES	N/A	YES	YES	N/A	YES	YES	YES

Source: by author

4. Discussions

4.1. Some issues on the Ostrom's framework

In Ostrom's framework, the criteria that invariably separates "failure" and "success" of institutions of CPRs is whether the stock level of CPRs would be maintained physically. The depletion of CPRs is regarded as an unsustainable state, and the factors that has caused the depletion are attributed to the "failure" of the institutional system. On the contrary, such institutions that can effectively avoid the depletion of CPRs are judged to be well-designed and supposed to persist for a long time. The point is that, in the Ostrom's framework, the performance of an institutional system is judged on the basis of the information of physically remaining stocks of CPRs and the persistence of the institutional system is evaluated in line with the design principles.

The Ostrom's framework is useful in the sense that it can offer methodologies for evaluating the sustainability of institutional systems of CPRs. However, it seems to have some drawbacks when it is applied to the practical drought management which was conducted in the Sanuki plain in 1994.

Firstly, the well-being of farmers in the Sanuki plain is excluded from the criteria to judge the performance of institutions and the "failure" of institutions should be evaluated based on the people's "capacity" of abstracting, appropriating, and distributing the resource units of CPRs. The performance of drought management in the Sanuki plain is judged on the basis of the physical amount of water resources that remains in ponds or Kagawa canal, however, the relationship between the remaining amount of water and the farmers' well-being is not questioned in the Ostrom's framework.

We do not argue that the condition of totally depleted stock of CPRs is unquestionably unsustainable, however, from the perspective of farmers' well-being, the level of their well-being may decrease if they do not have adequate facilities (e.g. water pumps, canals, water gates) or technologies (e.g. well-digging, construction method of water pipes) or knowledge (e.g. practices of agricultural irrigation) to have the stock of CPRs fully operational. We would like to argue here that there might be a case where the well-being of farmers whose capacity to utilize CPRs is severely restricted is decreasing even though the stock of CPRs has not been depleted. In this respect, the Ostrom's framework may be insufficient to judge the performance of institutions.

In the case of the Sanuki plain, it was reported after the extreme drought that the crop situation index of paddy yield among the members of the KCLID was greater than that of usual years. This may exemplify the fact that the amount of the remained water is certainly a determinant of well-being but not necessarily consonant with it.

Secondly, the design principles which offer criteria to evaluate the persistence of institutions does not include the perspective of passing down of implicit knowledge of farmers. This implicit knowledge includes various kinds of traditional practices of agricultural irrigation that enabled farmers to adapt to extreme drought effectively in the Sanuki plain in 1994. Some of these traditional practices had been once abandoned after the construction of the Kagawa canal in 1974. For example, a traditional practice of agricultural irrigation called "*senko-mizu,*" (*tokei-mizu*) which had been demolished after the construction of the Kagawa canal, was revived to distribute agricultural water according to the prearranged plan. In conjunction with a traditional practice of "*mizu-buni*," *senko-mizu* had made it possible for people in the Sanuki plain to manage the time of water intake to one's crop field strictly. *Mizu-buni* exhibited a farmer's appropriated amount of water and it had been recorded as the length of incense sticks. *Senko-mizu* was a system to fairly distribute water according to the mizu-buni. People could see the time limit for irrigating water to one's crop field by confirming the remaining length of incense sticks burned in a box. This practices had been implemented in the Sanuki plain in drought periods, however, it was gradually perceived as useless and declined after the construction of the Kagawa canal. It was not until 1994 that people in the Sanuki plain revived the practice of *senko-mizu*. The point was that the practice was a kind of implicit knowledge and it was revived by those people who were acquainted with the practice of *senko-mizu*. If the implicit knowledge of those people had been lost, the practice of *senko-mizu* would not have been reapplied in drought-prone areas in the Sanuki plain in 1994. This case suggests the importance of the accumulated implicit knowledge that enabled people to adapt to an unexpected extreme drought occurred in the Sanuki plain in 1994, and it is essential to consider what kind of an institutional system enables it to be passed down for generations.

4.2. Extending the Ostrom's framework

Now, we clarified above some issues of the Ostrom's framework when it is applied to the case of the drought management in the Sanuki plain which was implemented in 1994. We examine on this section the way to improve the Ostrom's framework by introducing the concept "productive base" that have been developed by P. Dasgupta in the literature of sustainable economic development (Dasgupta, 2004). Through the speculation in economic theory, Dasgupta (2004) has revealed that the net investment in the productive base, which consists of capital assets and institutions, is the determinant of the social well-being and if that is nonnegative, the path of an economic development can be evaluated as sustainable in the sense that the well-being per capita will be maintained over time. Capital assets are comprised of natural capital, man-made capital, human capital and knowledge. Institutions, considered as a resource allocation mechanism in the Dasgupta's framework, have an impact on the process of accumulating and combining those capital assets, expanding the state of people's well-being. Figure 3 illustrates the relationship between the "productive base" (capital assets and institutions) and well-being in the framework of sustainable economic development in Dasgupta (2004).

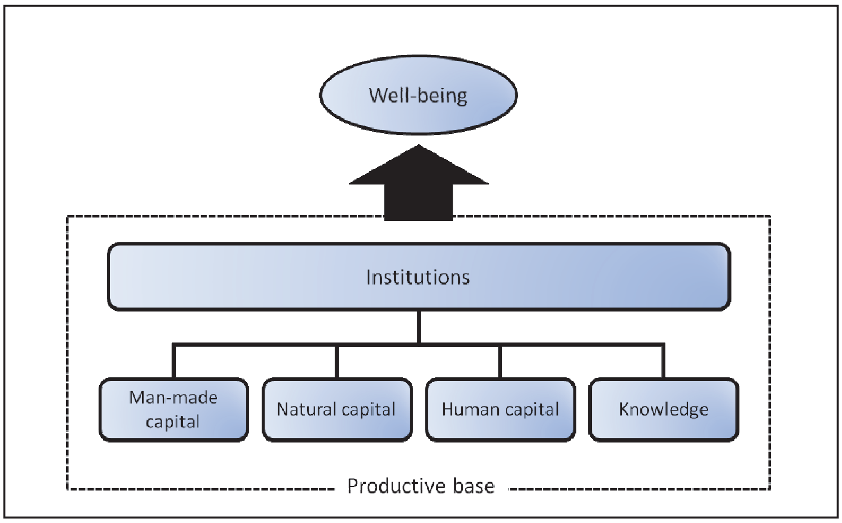

Figure 3: The relationship between "productive base" and human well-being

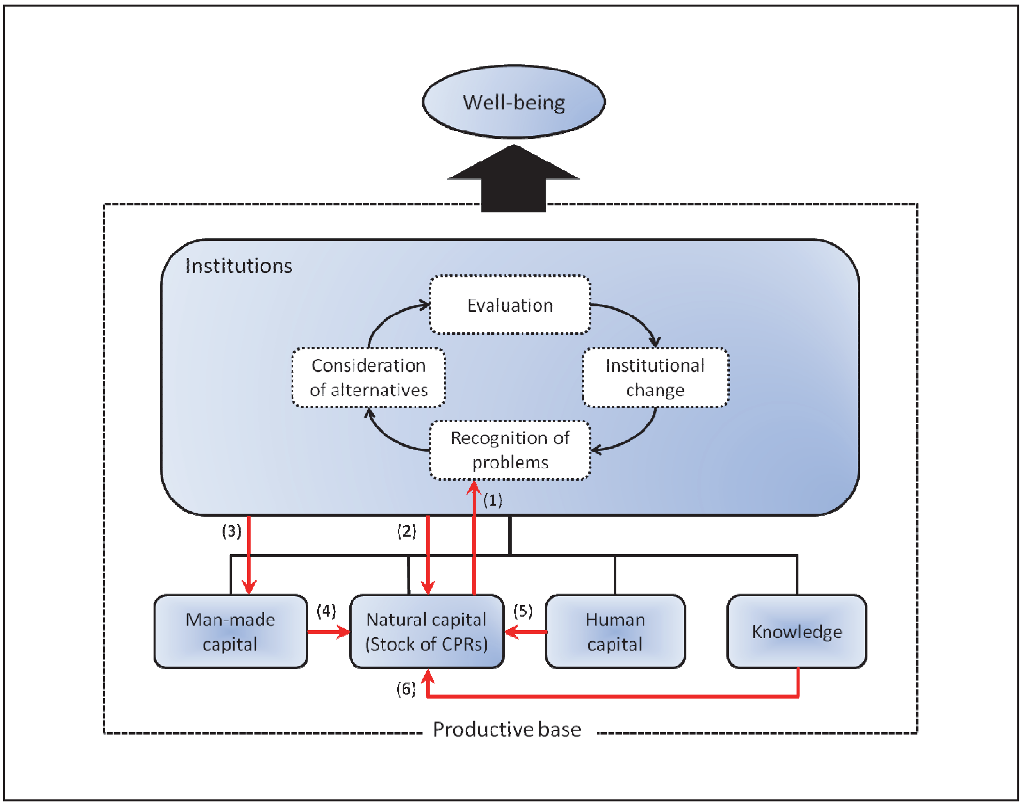

Figure 4: An extended analytical framework of sustainable management of CPRs

Figure 4 illustrates the analytical framework of sustainable management of CPRs by introducing the concept of productive base into the Ostrom's evolutionary framework of institutional change. On the context of the Sanuki plain, the process of adaptation to the extreme drought can be explained by using the framework as follows. Firstly, due to the unexpected drought, the depleting stock of the reservoir of local ponds or the Kagawa canal was recognized as a serious problem to people in the Sanuki plain (depicted as the arrow (1) in Figure 4). After the problem was recognized by the appropriators or administrators, a variety of emergent alternatives were considered and such an alternative that the expected benefit of it would outweigh the expected cost of it was chosen. As the result of this process of institutional change, the traditional practices of agricultural irrigation such as rotational irrigation (*bansui*) were implemented to control the water flow and avoid the depletion of the stocks of local ponds or Kagawa canal (depicted as the arrow (2) in figure 4); and the emergent countermeasure construction for drought adaptation that aimed to alleviate the farmer's economic burden on installing pipes or pumps, or on digging wells were legislated, accelerating the accumulation of man-made capital stock (depicted as the arrow (3)). This newly installed water-related facilities were utilized in conjunction with existing ones to enhance the efficiency of water use (as depicted as the arrow (4)).

Some traditional practices of agricultural irrigation also called for more local staffs whose task was to irrigate water to each crop field as planned (*suihai*) or to control the illegal manipulation of water gates (*matamori*). Through changing the assignment of local staffs, water resources were efficiently distributed from reservoir to crop fields (depicted as the arrow (5)). As we have discussed on the previous section, implicit knowledge on implementing *senko-mizu* or water-saving irrigations also played an important role of avoiding the depletion of local ponds (depicted as the arrow (6) in figure 4).

This integrated analytical framework is more inclusive than the Ostrom's framework in the sense that it can capture the whole performance of institutions and offer a guide for the way of maintaining human well-being in the context of CPRs management as a rule of passing down the productive base (not confined to CPRs or institutions) to the next generation.

5. Conclusions

This paper verified the validity of the design principles through focusing on the institutional adaptation to the extreme drought implemented in the Sanuki Plain in 1994, and examined the issues that the Ostrom's analytical framework has. It is clarified that:

1. the perspective of farmers' well-being is excluded from the criteria to judge the performance of institutions and the determinant of well-being will be confined to the stock of CPRs and;
2. the design principles does not include the perspective of passing down of implicit knowledge for generations that would be useful in an unexpected situation like the extreme drought occurred in the Sanuki Plain in 1994.

And we tried to extend the Ostrom's framework by introducing the "productive base" concept which was developed in the literature of sustainable economic development by Dasgupta (2001). The proposed framework in this paper is developed through the examination of a specific case in the Sanuki Plain and is still a preliminary one, however, we believe it will be useful in the following respects. Firstly, it can capture the whole performance of institutions by focusing the interrelationships between natural capital (stock of CPRs) and the surrounding capital assets (i.e. man-made capital, human capital and knowledge). Secondly, it can offer a guide for sustainable CPRs management as a condition of passing down the productive base to the next generation, not confined to a condition of maintaining the institutional system or the stock of CPRs. It might be difficult, at this stage, to conduct any quantitative analysis using this framework, but it surely offers an analytical framework of sustainable CPRs management. We will try to examine its effectiveness and issues through the application of the framework to other field studies.

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