

INCREASING SOCIAL DEMAND FOR PUBLIC ECOSYSTEM SERVICES OF IRRIGATION CANALS UNDER CLIMATE CHANGE AND URBANIZATION

AUGMENTATION DE LA DEMANDE SOCIALE POUR LES SERVICES ÉCOSYSTÉMIQUES PUBLICS DES CANAUX D'IRRIGATION DANS LE CADRE DU CHANGEMENT CLIMATIQUE ET DE L'URBANISATION

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ABSTRACT

Climate change and urbanization are increasing flood risk in paddy areas where irrigation, drainage, and local flood management are closely connected. In monsoon Asia, flood risk studies have mainly developed basin-scale assessments and adaptation measures for large river basins and floodplains. However, in urbanized paddy areas in Japan, agricultural canals are also required to regulate local flood risk through daily operation by Land Improvement Districts (LIDs). This paper discusses how agricultural water infrastructure should be understood and managed under such changing conditions, using the Kottsu irrigation project in Aichi Prefecture as a case study.

The case study showed that urbanization and changing rainfall conditions have increased inflow loads to agricultural canals and have added operational burdens related to flood risk reduction to existing irrigation management. Even as paddy fields have decreased, irrigation water must still be delivered to remaining farmland, while canals must also receive increased rainfall-driven inflows from urbanized areas. These findings indicate that the flood risk reduction function of paddy fields and agricultural water infrastructure is sustained not only by physical facilities, but also by continuous operation and management by the LID.

Based on this case, the paper argues that flood risk reduction should be understood not only as part of agricultural multifunctionality, but also as an ecosystem service sustained by local water management. This perspective clarifies two challenges: benefit-burden asymmetry between those who receive flood risk reduction benefits and those who bear management burdens, and the accumulation of future flood risk through limited recognition of flood risk. Finally, the paper discusses VESPa as a researcher-initiated case study that organizes ecosystem services into shareable information and provides an entry point for stakeholder discussion on sustainable water management in urbanized paddy areas.

Keywords: Climate change; urbanization; agricultural canals; agricultural water infrastructure; flood risk reduction.

RESUME

Le changement climatique et l'urbanisation augmentent les risques d'inondation dans les zones de rizières où l'irrigation, le drainage et la gestion locale des inondations sont étroitement liés. En Asie de la mousson, les études sur le risque d'inondation se sont principalement concentrées sur des évaluations à l'échelle du bassin versant et des mesures d'adaptation pour les grands bassins versants

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et les plaines inondables. Cependant, dans les zones de rizières urbanisées au Japon, les canaux agricoles sont également nécessaires pour régler le risque d'inondation locale grâce au fonctionnement quotidien des Districts d'amélioration des terres (LID). Cet article examine la manière dont les infrastructures hydrauliques agricoles doivent être comprises et gérées dans des conditions aussi changeantes, en utilisant l'étude de cas du projet d'irrigation de Kottsu, menée dans la préfecture d'Aichi.

L'étude de cas a montré que l'urbanisation et l'évolution des conditions pluviométriques ont augmenté les charges d'écoulement sur les canaux agricoles et ont ajouté des charges opérationnelles liées à la réduction des risques d'inondation à la gestion existante de l'irrigation. Même si les rizières ont diminué, l'eau d'irrigation doit encore être acheminée vers les terres agricoles restantes, tandis que les canaux doivent également recevoir des écoulements accrus des précipitations provenant des zones urbanisées. Ces résultats indiquent que la fonction de réduction des risques d'inondation des rizières et des infrastructures hydrauliques agricoles est soutenue non seulement par les ouvrages physiques, mais aussi par l'exploitation continue et la gestion par le LID.

Sur la base de ce cas, l'article soutient que la réduction des risques d'inondation doit être comprise non seulement comme une composante de la multifonctionnalité agricole, mais aussi comme un service écosystémique soutenu par la gestion locale de l'eau. Cette perspective clarifie deux défis : l'asymétrie bénéfice-charge entre ceux qui reçoivent des avantages de réduction du risque d'inondation et ceux qui supportent des charges de gestion, et l'accumulation du risque d'inondation futur par une reconnaissance limitée du risque d'inondation. Enfin, l'article traite de la VESPa en tant qu'une étude de cas initiée par des chercheurs qui organise les services écosystémiques en informations partageables et fournit un point d'entrée pour tenir des discussions avec les parties prenantes sur la gestion durable de l'eau dans les zones de rizières urbanisées.

Mots-clés : Changement climatique; Urbanisation; Canaux agricoles; Infrastructures hydrauliques agricoles; Réduction des risques d'inondation.

1. INCREASING GLOBAL FLOOD RISK AND FLOODING IN MONSOON ASIA

In monsoon Asia, paddy rice cultivation has historically developed under hot and humid temperature with seasonal rainfall. While field irrigation in arid and semi-arid regions mainly aims to supply water to compensate for soil moisture deficits, paddy field water management in monsoon Asia is closely associated with both irrigation and drainage. In this context, paddy fields and agricultural water infrastructure have supported rice production while also contributing to runoff regulation and flood risk reduction during rainfall events.

In recent years, flood risk has been increasing globally due to the growing frequency and intensity of extreme precipitation associated with climate change. The frequency and intensity of heavy precipitation events are likely to increase as global warming progresses, and floods remain one of the major disasters causing severe human and economic losses worldwide (IPCC, 2023). Against such increasing risks, conventional structural measures, such as dams and levees, have limitations in fully controlling increasingly extreme floods. Accordingly, growing attention has been paid to the flood risk reduction functions of land uses such as agricultural land and wetlands.

To discuss increasing flood risk under climate change, this paper adopts the IPCC risk framework of hazard, exposure, and vulnerability. In the context of flood risk, hazard refers to the frequency and magnitude of extreme rainfall and flooding; exposure refers to people, assets, and agricultural land located in flood-prone areas; and vulnerability refers to the susceptibility of exposed elements to damage and the lack of capacity to cope with hazardous events. Flood risk is shaped not only by the magnitude of hazards but also by the existence of exposed elements and their vulnerability. The IPCC report also emphasizes that vulnerability and exposure are dynamic and that limited awareness and impediments to information flow can amplify risk. Previous studies on paddy areas in monsoon Asia have mainly developed basin-scale assessments of flood hazards and agricultural damage under climate change and land-use change. Shrestha et al. (2019) assessed future flood damage to paddy fields in major river basins in Southeast Asia by combining climate model outputs with a rainfall–runoff–inundation model.

Budhathoki et al. (2024) developed agricultural economic risk curves for the Lower Chao Phraya River Basin using a large ensemble climate projection dataset. Shrestha et al. (2025) further incorporated land-use change, particularly the reduction of paddy field areas, into future agricultural damage assessment in the Solo River Basin, Indonesia. These studies provide important insights into the basin-scale assessment of hazards, exposure, and agricultural damage under climate and social changes. In these studies, adaptation and flood risk reduction options are often discussed in relation to basin-scale adjustments, including land-use management, cropping calendar adjustment, and large-scale river or drainage infrastructure. Triet et al. (2018) incorporated cropping calendars and land-use scenarios into risk-based flood management for paddy rice cultivation in the Mekong Delta. Rizaldi and Kure (2025) evaluated the flood risk reduction effects of river dredging and paddy field dams in the Upper Citarum River Basin, Indonesia, under future land-use and climate change scenarios. These approaches are valuable for flood risk assessment and planning in large river basins and extensive floodplains, and they provide important implications for paddy flood risk management in monsoon Asia.

Thus, previous studies in monsoon Asia have mainly developed around flood risk assessment based on large-scale hydrological and climate models, as well as basin-scale adaptation measures. These studies are essential for understanding paddy flood risk in large river basins and floodplains. However, flood risk management at smaller spatial and operational scales has not been sufficiently examined. In particular, less attention has been paid to the local decision-making and operational management processes through which agricultural water infrastructure sustains flood risk reduction functions in urbanized paddy areas.

2. FLOOD RISK STRUCTURE AND LID MANAGEMENT IN URBANIZED PADDY AREAS IN JAPAN

In contrast to the extensive floodplains of large river basins in Southeast Asia, urbanized paddy areas in Japan have a distinctive flood risk and water management structure shaped by steep topography, short runoff concentration times, and closely connected canal networks. In many Japanese irrigation districts, natural rivers flow into or intersect with agricultural canals, and the same canal network is involved in both irrigation water supply and drainage management. Under this structure, stable water delivery to remaining farmland and the removal of excess water during rainfall events must be managed within a closely connected canal system.

As illustrated in Figure 1, flood risk in such areas can increase through the combined effects of rainfall intensification and urbanization. Increased localized heavy rains and urbanization in the catchment basin change runoff patterns and increase peak runoff into agricultural canals. At the same time, urbanization in the beneficiary area concentrates population, buildings, and other assets around the canal network. This increases the number of people and assets that may be affected by flooding. In addition, the conversion of paddy fields into residential and industrial land can increase the susceptibility of exposed elements, while limited capacities for local risk recognition and response may further increase vulnerability. In this way, hazard, exposure, and vulnerability can increase simultaneously in urbanized paddy areas, leading to higher flood risk.

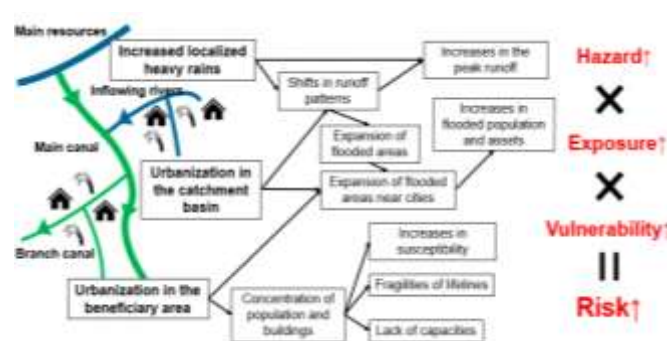


Figure 1. Conceptual flood risk structure in urbanized paddy areas in Japan.

Under these conditions, agricultural canals are increasingly required to support local flood risk regulation in addition to irrigation and drainage for agriculture. This role is particularly important in areas where inflowing rivers, main canals, branch canals, and urbanized land uses are closely connected.

The organizations responsible for maintaining and operating these complex canal networks are Land Improvement Districts (LIDs), which are farmer-based organizations in Japan. In many countries, farmer involvement in irrigation management has been discussed as participatory irrigation management (PIM), particularly in contexts where irrigation systems are largely managed by public agencies. In Japan, water management through LIDs has long been institutionalized, and LIDs have been regarded as good practices of PIM (Tanaka and Sato, 2005). Urbanization changes the operating conditions of LIDs. As non-agricultural land uses expand within beneficiary areas, drainage networks originally managed for agricultural production also receive stormwater runoff from urbanized areas. LIDs must therefore manage increased rainfall-driven inflows while maintaining irrigation and drainage for remaining farmland.

In Japan, the public functions of agricultural land and irrigation and drainage systems have often been discussed in relation to the multifunctionality of agriculture. This concept evaluates the additional benefits of agriculture beyond food production, including flood prevention, groundwater recharge, soil conservation, landscape formation, and biodiversity conservation. In urbanized paddy areas, these functions are closely tied to continuous water management under changing hydrological and land-use conditions. Therefore, this paper examines how urbanization and changing rainfall conditions increase hydrological loads on agricultural canals and how LIDs respond through operational management.

3. THE CASE STUDY OF THE KOTTSU IRRIGATION PROJECT

This chapter analyzes the Kottsu irrigation project as a case study of operational water management in an urbanized paddy area. It examines increases in inflow loads caused by urbanization and changes in rainfall conditions and evaluates corresponding changes in the operational burden of the LID in this area.

3.1 Study Area

The Kottsu irrigation area is located around Komaki City and Kasugai City, in Aichi Prefecture, Japan. In this area, urbanization has led to the mosaic conversion of farmland into residential and commercial land. The assessed paddy field area of the LID has decreased substantially over the long term, indicating significant land-use change in a suburban paddy area.

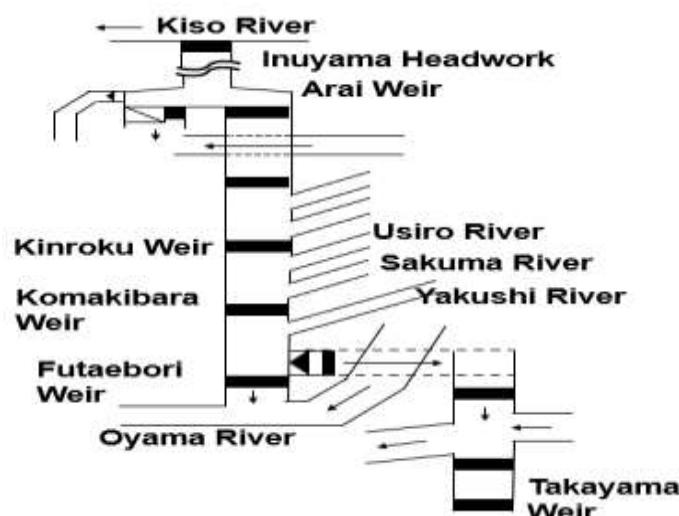


Figure 2. Overview of the Kottsu irrigation project.

As shown in Figure 2, the Kottsu irrigation canal takes water from the Kiso River and delivers irrigation water to the beneficiary area through its main canal network. In the downstream part of the canal, several natural rivers and drainage channels intersect or merge with agricultural canals, and their inflows strongly affect canal water levels during rainfall events. In particular, the Shin-Kottsu Canal includes sections where inflowing rivers directly enter the main canal, as well as sections where agricultural canals and natural rivers function in an integrated manner. The Kottsu irrigation project is therefore a case where irrigation management and rainfall-response operations overlap within the same canal network.

3.2 Increase in Inflow Loads under Urbanization and Changing Rainfall Conditions

In the catchment basin of the main canal, urbanized land increased from 1976 to 2016, as highly permeable land uses such as farmland were converted into residential and industrial land. This expansion of impervious surfaces created conditions that increase surface runoff during rainfall events. In this study, runoff analysis using a tank model was conducted to evaluate the effects of land-use change and rainfall change on inflows to the Shin-Kottsu Canal. A comparison between past and present land-use conditions under rainfall events corresponding to the same return period showed that both increased rainfall intensity and the expansion of impervious surfaces contributed to higher peak discharge. Under the 2016 conditions, the maximum peak discharge was approximately 1.67 times that under the 1976 conditions, with an increase of about 7.7 m³/s. These results indicate that inflow loads to the Shin-Kottsu Canal have increased due to both changing rainfall conditions and urbanization. In other words, the LID is now required to manage larger peak flows than in the past within limited canal capacity.

3.3 Long-term Increase in Operational Burden

Next, changes in the operational burden of the LID were evaluated using gate operation records from management logs. The analysis focused on three major weirs located along the main canal of the Kottsu irrigation project: Arai Weir, Futaebori Weir, and Takayama Weir. These weirs play an important role in water level regulation and flow distribution across the canal system, and the number of gate operations can therefore be used as an indicator of the field-level operational burden borne by the LID.

This study extracted gate operation records at the three major weirs from management logs for 1994–1998 and 2017–2021 and compared the number of operations between the two periods. The purpose of each operation was also classified as either irrigation-related or flood-control-related based on rainfall intensity on the day of operation.

The total number of gate operations at the three major weirs increased from 3,358 in the past period to 4,974 in the present period. By operation purpose, the number of irrigation-related operations did not show a large change between the two periods. Although farmland has decreased with urbanization, the operational burden for irrigation has not decreased substantially. This is because remaining farmland is distributed in a mosaic pattern among residential and industrial land uses. To maintain irrigation water delivery to these remaining fields, the canal network must continue to be operated, and a reduction in farmland area does not directly lead to a proportional reduction in irrigation management burden.

In contrast, the number of flood-control-related operations during rainfall events increased substantially from the past to the present period. During heavy rainfall events, multiple gate operations were conducted to suppress rises in canal water levels, and fine adjustments were sometimes repeated within a single rainfall event. These results show that urbanization does not simply reduce the management burden of the LID. Rather, flood-control-related operational burden has been added to existing irrigation management.

3.4 Complexity of Operational Decisions

Field-level operations in the Kottsu irrigation project involve complex decisions to balance irrigation supply and flood risk reduction during rainfall events. Operators need to monitor rainfall forecasts and canal water levels while anticipating inflows from upstream rivers. They must lower water levels to

prevent overtopping into urbanized areas, but excessive lowering can affect irrigation supply to remaining farmland after the rainfall event. Operational decisions are therefore made under a trade-off between flood risk reduction and irrigation supply.

In addition, because changes in gate openings propagate downstream with time lags, operators must anticipate when and how each operation will affect downstream water levels. Management logs and interviews also confirmed emergency responses, including gate operations from late night to early morning and siphon closure operations. These operations are different from routine water distribution and involve immediate decisions to avoid overtopping during rainfall events.

The analysis showed that increased inflow loads have led to more frequent and complex operations by the LID. These results provide a basis for discussing challenges for sustainable water management in urbanized paddy areas.

4. CHALLENGES FOR SUSTAINABLE WATER MANAGEMENT

4.1 Benefit–Burden Asymmetry

The results from the Kottsu irrigation project indicate that operations by the LID are required not only for irrigation and drainage, but also for reducing local flood risk under urbanization and changing rainfall conditions. This raises the question of who benefits from these flood risk reduction effects and who bears the burden of maintaining them.

Osawa (2022) pointed out that when agricultural infrastructure contributes to urban flood risk reduction beyond its original purpose, a structural gap can emerge between those who receive the benefits and those who bear the costs and risks. The situation of LIDs in urbanized paddy areas in Japan can be understood as an important case of this asymmetry between beneficiaries and burden bearers.

One approach to addressing this asymmetry is public support for the management of agricultural water infrastructure. Such support can be interpreted as a way of sustaining flood risk reduction benefits as benefits to society as a whole. In Japan, public financial support schemes for the management of key irrigation and drainage facilities have been implemented, and these schemes can reduce part of the burden borne by LIDs.

Another approach is to connect beneficiaries and burden bearers more directly through cost-sharing or payment schemes. Sawata et al. (2022) proposed a method for estimating the appropriate share of urban-side costs for the maintenance of agricultural drainage facilities in urbanized low-lying paddy areas, based on land-use-specific runoff characteristics. Yoshikawa and Koshiyama (2024) also emphasized that sustainable implementation of Tambo Dam practices requires administrative schemes and incentives that support farmers' maintenance and management efforts. These studies suggest that institutional arrangements can help connect those who receive flood risk reduction benefits with those who bear the burden of maintaining them.

Public support and payment schemes are therefore important for addressing benefit–burden asymmetry. However, these approaches depend on a shared understanding of what benefits are being provided, who receives them, and what management burden is required to maintain them. This point leads to the need to reconsider how the flood risk reduction function of agricultural water infrastructure is conceptualized.

4.2 Accumulation of Future Flood Risk

The flood risk reduction role of agricultural water infrastructure also has implications for future flood risk. When operations by LIDs successfully prevent overtopping or inundation, the avoided damage is not directly observed by residents. As a result, residents may not fully recognize the flood risk that remains even after water management, or the role played by agricultural water infrastructure in reducing that risk.

Flood risk studies have shown that successful flood protection can sometimes increase future risk through changes in land use and risk perception. White (1945) pointed out that flood protection may encourage settlement and development in flood-prone areas by making them appear safer. This process has later been discussed as the levee effect or the safe-development paradox (Di Baldassarre et al., 2013). The IPCC also emphasizes that risk communication, risk perception, and information flows influence vulnerability and disaster risk.

In urbanized paddy areas, a comparable process may occur when management by LIDs successfully reduces visible flood damage. Limited recognition of flood risk can allow further concentration of population and assets around the canal network, thereby increasing exposure. In addition, the conversion of paddy fields into residential or industrial land can increase the susceptibility of exposed elements, because urban assets generally suffer larger damage than agricultural land under similar inundation conditions.

Limited recognition of flood risk can also weaken local coping capacity. If residents do not sufficiently recognize flood risk or the role of agricultural water management, preparedness, emergency response, and risk communication may remain limited. Komori et al. (2025) similarly suggested that limited recognition of increased flood risk after land-use change from paddy fields to residential areas can weaken local coping capacity.

In urbanized paddy areas, limited recognition of flood risk may therefore allow exposure and vulnerability to accumulate over time. Sustainable flood risk management requires processes through which residents recognize the flood risk that remains after water management and the role of agricultural water management.

4.3 From Multifunctionality to Ecosystem Services

The two challenges discussed above suggest the need to reconsider how the flood risk reduction function of paddy fields and agricultural water infrastructure is understood. In Japan, such functions have often been discussed in relation to the multifunctionality of agriculture. This concept has been useful for recognizing the public value of agriculture and rural areas beyond food production.

However, in urbanized paddy areas, flood risk reduction should be understood not only as a secondary public function associated with agricultural production, but also as an ecosystem service sustained by continuous operation and management by LIDs. This perspective is important because flood risk reduction in these areas is not supplied solely by the existence of paddy fields or canals. It is maintained through water-level control, facility operation, and management decisions under changing hydrological and land-use conditions.

The ecosystem services perspective helps clarify the relationship between service provision, beneficiaries, and management burdens. It asks not only whether paddy fields and agricultural water infrastructure reduce flood risk, but also how this service is supplied, who benefits from it, and who bears the burden of maintaining it. This perspective also makes it possible to discuss the flood risk that remains after water management, because recognizing flood risk reduction as a service requires an understanding of both its contribution and its limits. Introducing an ecosystem services perspective makes the supply process, beneficiaries, burden bearers, and the flood risk that remains after water management more explicit. This provides a basis for addressing both benefit–burden asymmetry and the accumulation of future flood risk.

4.4 Toward an Integrated Approach

The preceding sections identified two related challenges: benefit–burden asymmetry and the accumulation of future flood risk. Although these challenges concern different aspects of water management, both require shared recognition of the functions, burdens, and limits of agricultural water management. Sustainable water management in urbanized paddy areas therefore requires an approach that connects institutional arrangements with risk recognition.

Such an approach should make three elements shareable among stakeholders: the flood risk reduction service provided by agricultural water infrastructure, the management burden borne by LIDs, and the flood risk that remains after water management under urbanization and changing rainfall conditions. Sharing these elements can support institutional responses to benefit–burden asymmetry, including public support and cost-sharing discussions. It can also support risk-management responses by improving recognition of flood risk and local coping capacity.

This shared understanding also provides a basis for discussing how local water management should be supported by a wider range of stakeholders.

5. VESPA AS AN ENTRY POINT FOR INTEGRATED WATER MANAGEMENT

5.1 Positioning of VESPa as a Case Study

This chapter introduces VESPa as a case study in the Kottsu irrigation area. VESPa is a researcher-initiated project that seeks to organize the ecosystem services provided by paddy fields and agricultural water infrastructure into information that can be shared among local stakeholders. In this paper, VESPa is positioned as an entry point for connecting agricultural water management with local discussion on sustainable water management.

The current VESPa approach focuses on making the functions of paddy fields and agricultural water infrastructure easier to understand and discuss. By presenting these functions as ecosystem services, it can help stakeholders recognize that agricultural water infrastructure supports not only agricultural production but also local flood risk reduction. This provides a basis for discussing how such services are maintained, who supports them, and what risks remain under urbanization and climate change.

5.2 VESPa Approach to Shared Recognition

VESPa contributes to shared recognition by organizing the functions of paddy fields, canals, and related facilities as ecosystem services. In urbanized paddy areas, agricultural water infrastructure is often understood mainly as infrastructure for irrigation and drainage. Presenting its flood risk reduction role as an ecosystem service can broaden this understanding and provide a common basis for discussion among LIDs, local governments, and residents.

This approach is relevant to the issues discussed in the previous chapter. Recognition of ecosystem services can support discussion on benefit–burden asymmetry by clarifying that flood risk reduction benefits extend beyond agricultural production. It can also provide an entry point for communicating the flood risk that remains after water management, because recognizing the flood risk reduction role of agricultural water infrastructure also requires understanding its limits. In this sense, VESPa can connect ecosystem service evaluation with local discussion on management support and risk communication.

5.3 Toward Participatory Water Management

The VESPa case study also suggests direction for participatory water management in urbanized paddy areas. Japan has a long history of farmer-based water management through LIDs and participatory irrigation management. Under urbanization, however, the beneficiaries of agricultural water infrastructure have expanded beyond farmers. This creates a need for water management discussions that include local governments, residents, and other non-agricultural actors.

Participation in this context does not necessarily mean direct involvement in facility operation. It can include understanding the role of agricultural water infrastructure, sharing information on flood risk, discussing support schemes, and cooperating in local disaster risk reduction. By making ecosystem services easier to recognize and discuss, VESPa can provide an entry point for involving a wider range of stakeholders in sustainable water management.

6. CONCLUSION

This paper examined how agricultural water infrastructure in urbanized paddy areas in Japan is required to support local flood risk regulation under climate change and urbanization. The case study of the Kottsu irrigation project showed that inflow loads to canals have increased due to urbanization and changing rainfall conditions, and that the operational burden of the LID has also increased. Even as paddy fields have decreased, irrigation water still needs to be delivered to remaining farmland. Urbanization therefore does not simply reduce irrigation management burdens; it adds operational burdens related to flood risk reduction to existing irrigation management.

The challenges identified in this paper are twofold. First, flood risk reduction benefits provided through water management by LIDs extend beyond agricultural production, while the management burden required to sustain these benefits tends to remain concentrated on LIDs. This creates benefit–burden asymmetry between those who receive flood risk reduction benefits and those who bear the costs and risks of maintaining them. Second, when management by LIDs successfully prevents overtopping or inundation damage, residents may have limited recognition of flood risk. This limited recognition can allow exposure and vulnerability to accumulate over time through the concentration of population and assets around canals and through insufficient risk recognition and coping capacity.

These challenges suggest the need to understand the flood risk reduction function of paddy fields and agricultural water infrastructure not only as part of agricultural multifunctionality, but also as an ecosystem service sustained by continuous operation and management by LIDs. The ecosystem services perspective clarifies how flood risk reduction is supplied, who benefits from it, who bears the management burden, and what flood risk remains after water management. This provides a basis for discussing public support, cost-sharing schemes, risk communication, and broader stakeholder involvement in local water management.

VESPa is presented as a case study that can support this direction by organizing ecosystem services into shareable information. It provides an entry point for stakeholder discussion on agricultural water management, including management burdens and the flood risk that remains after water management. These findings provide implications for decision-making processes in local water management. Sustainable management of agricultural water infrastructure under urbanization and climate change requires mechanisms for sharing its functions, management burdens, and the flood risk that remains after water management within local society. Agricultural water infrastructure should therefore be recognized as water management infrastructure that supports the wider local society, forming an important basis for sustainable water management in urbanized paddy areas.

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