

BARRIERS TO AWD ADOPTION IN GRAVITY-FED IRRIGATION SYSTEMS AND PERSPECTIVES FOR FUTURE IMPLEMENTATION

OBSTACLES À L'ADOPTION DE L'AWD DANS LES SYSTÈMES D'IRRIGATION GRAVITAIRE ET PERSPECTIVES DE MISE EN ŒUVRE FUTURE

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ABSTRACT

AWD is a water management technique that simultaneously reduces methane emissions from paddy fields and conserves irrigation water, yet its adoption remains markedly skewed by irrigation type: stagnant under gravity-fed systems—which account for the majority of the world's irrigated paddy—while progressing relatively smoothly under pump-fed systems. Although previous studies have individually illuminated various determinants, few have systematically organized these factors as structural characteristics inherent to gravity-fed irrigation itself. This study aims to systematically identify the barriers to AWD adoption in gravity-fed irrigation through a comparison with pump-fed irrigation. Using SWOT analysis as the analytical framework, we extracted the strengths, weaknesses, opportunities, and threats of both irrigation types from cases in three countries (the Philippines, Bangladesh, and Vietnam), and derived strategies through a TOWS matrix. The analysis reveals that the core barrier lies in a structural mismatch: decision-making authority over water management rests with the collective (water user organizations), whereas promotion-scheme incentives target individual farmers. This mismatch—absent in pump-fed systems, where authority and incentive beneficiaries coincide—cannot be overcome merely by changing the type of economic incentive. Because the greenhouse-gas-reduction effect of AWD is a global externality scarcely returned to individual farmers, external payment is justified; and because authority is collective in gravity-fed systems, that payment should be designed as a collective Payment for Ecosystem Services (PES) directed to water user organizations, thereby aligning decision-making authority with beneficiaries. However, such collective incentive design depends on a prerequisite: the establishment of methods to quantitatively evaluate AWD effects at the irrigation-district scale, since current individual-field-level measurement cannot provide a payment basis. The collective governance of gravity-fed irrigation is thus simultaneously a weakness and a latent strength for wide-area AWD implementation.

Keywords: Water management technique; Gravity-fed irrigation; Economic incentive; Individual farmers; Collective governance.

RÉSUMÉ

L'AWD est une technique de gestion de l'eau qui réduit simultanément les émissions de méthane des rizières et économise l'eau d'irrigation. Son adoption demeure toutefois très inégale selon le type d'irrigation : elle stagne dans les systèmes gravitaires — qui représentent la majorité des rizières irriguées dans le monde — alors qu'elle progresse relativement facilement dans les systèmes alimentés par pompage. Bien que des études antérieures aient mis en lumière divers déterminants pris séparément, rares sont celles qui ont organisé systématiquement ces facteurs comme des

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caractéristiques structurelles inhérentes à l'irrigation gravitaire elle-même. Cette étude vise à identifier systématiquement les obstacles à l'adoption de l'AWD dans l'irrigation gravitaire en la comparant à l'irrigation alimentée par pompage. En utilisant l'analyse SWOT comme cadre analytique, nous avons extrait les forces, les faiblesses, les possibilités et les menaces propres aux deux types d'irrigation à partir de cas dans trois pays (Philippines, Bangladesh et Vietnam), puis élaboré des stratégies au moyen d'une matrice TOWS. L'analyse révèle que l'obstacle central réside dans une inadéquation structurelle : le pouvoir décisionnel en matière de gestion de l'eau appartient au collectif (organisations d'usagers de l'eau), tandis que les incitations des programmes de promotion ciblent les agriculteurs individuellement. Cette inadéquation — absente des systèmes alimentés par pompage, où le détenteur du pouvoir et les bénéficiaires des incitations coïncident — ne peut être surmontée par un simple changement du type d'incitation économique. Comme l'effet de réduction des gaz à effet de serre de l'AWD constitue une externalité mondiale dont les agriculteurs individuels ne bénéficient guère, un paiement externe est justifié ; et puisque le pouvoir est collectif dans les systèmes gravitaires, ce paiement devrait prendre la forme d'un paiement collectif pour services écosystémiques (PSE) destiné aux organisations d'usagers de l'eau, afin d'aligner le pouvoir décisionnel sur les bénéficiaires. Cependant, la conception d'une telle incitation collective dépend d'un préalable : la mise au point de méthodes permettant d'évaluer quantitativement les effets de l'AWD à l'échelle du district d'irrigation, car les mesures actuellement réalisées à l'échelle des parcelles individuelles ne peuvent fournir une base de paiement. La gouvernance collective de l'irrigation gravitaire constitue donc à la fois une faiblesse et un atout latent pour la mise en œuvre de l'AWD à grande échelle.

Mots clés : Technique de gestion de l'eau; Irrigation gravitaire; Incitation économique; Agriculteurs individuels; Gouvernance collective.

1. INTRODUCTION

Methane emissions from paddy fields account for a substantial share of global anthropogenic methane emissions, and their reduction has become an international priority from the perspective of climate change mitigation. Alternate Wetting and Drying (AWD) is a water management technique in which paddy fields are periodically dried and re-flooded during the growing season. Compared with conventional continuous flooding, AWD has been reported to substantially reduce both methane emissions and irrigation water use (Bouman et al., 2007; Carrijo et al., 2017). AWD is thus a technique that delivers two effects at once—the reduction of greenhouse gas (GHG) emissions and the conservation of water resources—and its dissemination has been pursued for many years, led by the International Rice Research Institute (IRRI).

Despite these expected benefits, the social implementation of AWD is known to be heavily skewed by irrigation type. In regions where gravity-fed irrigation—which accounts for the majority of the world's irrigated paddy fields—is dominant, adoption has stagnated markedly, whereas in regions where pump-fed irrigation is dominant, adoption has tended to progress relatively smoothly (Enriquez et al., 2021; Le, 2020; Ong et al., 2025). Previous studies on the determinants of AWD adoption have repeatedly emphasized that economic incentives—such as reductions in fuel and irrigation water costs—are important drivers of adoption (Lampayan et al., 2015; Rejesus et al., 2011; Chakravorty et al., 2020). Meanwhile, in gravity-fed irrigation, the water management discretion of individual farmers is reported to be restricted under rotational irrigation operated by Irrigators' Associations (IAs) (Samoy-Pascual et al., 2022; Enriquez et al., 2021).

These previous studies have individually illuminated various aspects of the stagnant adoption of AWD in gravity-fed irrigation. However, few studies have systematically organized these factors and identified them as structural characteristics inherent to gravity-fed irrigation itself. In particular, there has been a lack of integrated analysis that, through comparison with pump-fed irrigation, evaluates which of the structural characteristics of gravity-fed systems hinder AWD adoption and which elements can conversely be leveraged as strengths.

This study therefore aims to systematically identify the barriers to AWD adoption in gravity-fed irrigation systems. Adopting SWOT analysis as the analytical framework, it extracts the SWOT of gravity-fed and pump-fed irrigation from cases in three countries (the Philippines, Bangladesh, and Vietnam). The SWOT of pump-fed irrigation is positioned as a point of comparison for identifying characteristics that gravity-fed systems lack and strengths that can be leveraged. Furthermore, using a TOWS matrix, strategies are derived from combinations of these elements to present directions for institutional design that can promote AWD adoption in gravity-fed irrigation. Through this analysis, the study clarifies how the governance structure characteristic of gravity-fed irrigation affects AWD adoption and provides insights that contribute to designing dissemination strategies tailored to the type of irrigation system.

2. METHODS

2.1 Target Cases

This study conducted a literature review of cases in three countries where AWD promotion projects have been implemented. Cases were selected on the basis of ensuring diversity in irrigation type and governance structure, and the following three cases were chosen.

Philippines. The analysis focused on cases within the Upper Pampanga River Integrated Irrigation System (UPRIIS, command area of 119,640 ha), a large-scale state-run gravity-fed irrigation system in Central Luzon. UPRIIS is a publicly operated gravity-fed irrigation system managed by the National Irrigation Administration (NIA), in which the irrigation schedule is determined by rotational irrigation operated by Irrigators' Associations (IAs), the relevant farmer organizations. Since 2002, IRRI, PhilRice, and NIA have continuously implemented dissemination activities such as technical training and demonstration plots, and in 2009 Administrative Order 25 of the Department of Agriculture positioned AWD as a national water-saving technology. The main sources for this case were empirical studies in UPRIIS by Samoy-Pascual et al. (2022) and Enriquez et al. (2021), as well as reports on dissemination projects such as Lampayan et al. (2015).

Bangladesh. The analysis focused on the deep-tubewell irrigation project operated by the Barind Multipurpose Development Authority (BMDA) in the Barind region in the northwest. Pump-fed irrigation relying on groundwater as the main water source is dominant in this region, and BMDA operates an hourly volumetric pay-per-use system through prepaid-card-enabled meters installed on each pump. As of July 2018, more than 7,000 pumps were connected to prepaid meters. In the dissemination of AWD, early demonstration trials were conducted by IRRI and BRRI (from 2004 onward). The main sources were the randomized controlled trial by Chakravorty et al. (2020) and the institutional analysis by Vu et al. (2023).

Vietnam. The analysis focused on the World Bank–supported Vietnam Sustainable Agriculture Transformation (VnSAT) project, implemented from 2015 in eight provinces of the Mekong Delta. Centered on the 1 Must Do, 5 Reductions (1M5R) package, VnSAT provided technical training and demonstration plots to farmer organizations, subsidies, and support for small-scale infrastructure development, while economic incentives were established through contract farming that enabled rice to be sold at premium prices. Through these measures, more than 150,000 farmers across the eight provinces of the Mekong Delta received training. A notable feature of this project is that gravity-fed and pump-fed irrigation areas coexist within its scope, enabling a comparison across irrigation types within the same project. The main sources were Le (2020) and Ong et al. (2025).

The characteristics of these three cases are summarized in Table 1. In all three cases, dissemination activities such as technical training, training of extension workers, and the establishment of demonstration plots were commonly implemented, along with additional measures tailored to each country's irrigation and economic environment. However, the adoption status of AWD differs markedly among the cases. The following chapter examines the factors that generate these differences through a SWOT analysis by irrigation type.

Table 1. Comparison of AWD promotion projects across countries.

Country / Project	Target Region	Irrigation Type	Water Management Decision-Making	Adoption
Philippines (NIA, PhilRice, etc.)	UPRIIS, etc.	Gravity-fed	Collective (IA)	Stagnant
Bangladesh (BMDA)	Barind region	Pump-fed (deep tubewell)	Individual	Established
Vietnam VnSAT (pump-fed areas)	Mekong Delta (8 provinces)	Pump-fed	Individual	Established
Vietnam VnSAT (gravity-fed areas)	Mekong Delta (8 provinces)	Gravity-fed	Collective (cooperatives, etc.)	Stagnant

2.2 Analytical Framework: SWOT–TOWS Analysis

This study places SWOT analysis at the core of its analytical framework and derives strategies using a TOWS matrix. SWOT analysis is a method that organizes the four elements possessed by a target system—Strengths, Weaknesses, Opportunities, and Threats—along two axes (internal/external factors and positive/negative factors), and it is widely used as a preliminary step in strategy formulation (Helms and Nixon, 2010). In the field of agricultural water management as well, its effectiveness in structurally capturing complex water resource management issues has been demonstrated, for example, by Lazaridou et al. (2019) in their analysis of irrigation issues in the Nestos River basin in Greece, and by Nagara et al. (2015) in their comparison of alternative water resource solutions in Asia and Africa.

The axes of the SWOT analysis in this study are defined as follows.

- **Internal factors:** the structural characteristics of the irrigation system itself (physical infrastructure, governance structure, the locus of farmers' decision-making authority, etc.).
- **External factors:** the policy, market, and technological environment surrounding the irrigation system. These are organized as the environment that both irrigation types commonly face.
- **Positive / Negative:** advantages and disadvantages in the context of AWD adoption.

Note that this study extracts SWOT at the level of two system types—gravity-fed irrigation and pump-fed irrigation—rather than for individual irrigation systems. That is, for internal factors, the characteristics that each irrigation type commonly possesses are organized across cases, and for external factors, the external environment that both types may face is organized across cases. The pump-fed SWOT is positioned as a point of comparison for identifying characteristics that gravity-fed systems lack and strengths that can be leveraged. By contrasting the two, the structural characteristics inherent to gravity-fed irrigation are clarified.

Finally, using a TOWS matrix, strategies were derived from combinations of the SWOT elements. The TOWS matrix is an extension of SWOT analysis and is a method for extracting concrete action strategies from combinations of internal and external factors (SO, ST, WO, WT) (Wehrich, 1982). In recent years, SWOT–TOWS analysis has been applied in the field of agriculture and water resource management—for example, to the formulation of agricultural strategies under climate change (Nguyen et al., 2022)—demonstrating its effectiveness in organizing the complex interests among stakeholders and institutional constraints and in guiding the design of effective policies and institutions.

2.3 Analytical Procedure

The analysis was conducted in the following three stages.

Stage 1: Organizing case characteristics

For the three cases described above, information was extracted from the perspectives of irrigation type, the locus of water management decision-making authority, and the adoption status of AWD, and organized as shown in Table 1. In addition, the dissemination activities implemented in each case and the measures tailored to each country's irrigation and economic environment were described in Section 2.1.

Stage 2: SWOT analysis by irrigation type

Cases were classified into gravity-fed irrigation (UPRIIS in the Philippines and the gravity-fed areas of VnSAT in Vietnam) and pump-fed irrigation (the Barind region in Bangladesh and the pump-fed areas of VnSAT), and the four SWOT elements were extracted for each. In extracting each element, the impact on AWD adoption and dissemination was used as the criterion. External factors were organized as items common to both irrigation types.

Stage 3: Strategy derivation through the TOWS matrix and identification of barriers

Each SWOT element was examined qualitatively, and a TOWS matrix was constructed centered on the elements judged to be inherent to gravity-fed irrigation and to have a large impact on AWD adoption through comparison with pump-fed irrigation, from which the SO, ST, WO, and WT strategies were derived. Through examination of the derived strategies, the structural barriers to AWD adoption in gravity-fed irrigation and the institutional requirements necessary to overcome them were identified.

3. RESULTS

3.1 SWOT Analysis of Gravity-Fed Irrigation

Table 2 presents the strengths and weaknesses of gravity-fed irrigation extracted from the cases of UPRIIS in the Philippines and the gravity-fed areas of VnSAT in Vietnam. Because Opportunities and Threats constitute the external environment common to both irrigation types, they are described together in Section 3.3.

Table 2. SWOT analysis of gravity-fed irrigation.

	Positive Factors	Negative Factors
Internal Factors (structural characteristics of the irrigation system)	Strengths (S1–S2) - S1: A collective governance structure in which water user organizations oversee water management decision-making for the entire irrigation area - S2: Suitability for collective MRV and carbon crediting	Weaknesses (W1–W4) - W1: The water management discretion of individual farmers is severely limited - W2: Mismatch between the locus of decision-making authority (collective) and the beneficiaries of promotion-scheme incentives (individuals) - W3: Irrigation fees are often fixed or free, so the benefits of water saving rarely accrue - W4: Difficulty of coordinating rotational irrigation with the AWD cycle

Strengths

As a strength, gravity-fed irrigation has a collective governance structure in which water user organizations oversee decision-making for the entire irrigation area (S1), a foundation that enables wide-area decision-making difficult on an individual-farmer basis. In UPRIIS in the Philippines, the entire 119,640-ha irrigation area is managed through rotational irrigation by IAs, and in the gravity-fed areas of VnSAT in Vietnam, collective organizations such as cooperatives are responsible for water management (Ong et al., 2025). Such organizations are already equipped with existing resources such as water-distribution control facilities and regular meetings, providing the groundwork for the coordination and monitoring systems required for AWD. Moreover, wide-area synchronized AWD under this structure is well suited to collective measurement, reporting, and verification (MRV) of methane reduction, making scaling in carbon crediting easier than MRV at the individual-farmer level (S2).

Weaknesses

The most pronounced weakness is that the authority to make water management decisions belongs to a collective such as a water user organization, limiting individual farmers' discretion to implement AWD (W1): because gravity-fed systems distribute water from upstream to downstream through shared canals, individual farmers cannot independently control the timing of intake and drainage in their own fields. Samoy-Pascual et al. (2022) empirically showed that in UPRIIS only 22% of farmers can determine their own irrigation schedule, and Le (2020), through a survey of 250 farmers in the Mekong Delta, found that collective pump management has a significant negative effect on AWD adoption. These findings reflect the mismatch (W2) between the locus of decision-making authority (collective) and the beneficiaries of promotion-scheme incentives (individuals).

What is important here is that the incentives in W2 refer to benefits conferred by promotion schemes such as fee exemptions or PES, which are distinct from the benefits of the effects (water saving and GHG reduction) of AWD itself. In gravity-fed systems, because such scheme incentives are directed at individual farmers while decision-making authority lies with the collective, schemes targeting individuals do not translate into behavioral change.

Furthermore, in gravity-fed irrigation, a fee structure in which water saving is unlikely to translate into economic benefits is common (W3). In pump-fed systems, pumping fuel and electricity costs are proportional to the volume withdrawn, so water saving is directly returned to farmers as cost reduction; by contrast, in gravity-fed systems, fees are often charged at a fixed rate by area or made free through public subsidies, so reducing withdrawal does not change the farmer's cost burden. The fee exemption for farmers with 8 ha or less under the Philippines' 2018 Free Irrigation Service Act (Republic Act 10969) is an extreme example. In addition, in systems operating rotational irrigation, the need for technical coordination between the water-distribution schedule and the drying/re-flooding cycle of AWD is also a weakness (W4).

3.2 SWOT Analysis of Pump-Fed Irrigation

For comparison, Table 3 presents the SWOT of pump-fed irrigation extracted from the cases of the Barind region in Bangladesh and the pump-fed areas of VnSAT in Vietnam.

Strengths

The greatest strength of pump-fed irrigation is that, because the authority over water management decisions belongs to individual farmers (PS1), the locus of decision-making authority and the beneficiaries of promotion-scheme incentives structurally coincide (PS2). As a result, water-saving behavior is directly returned to individual farmers as economic benefits (such as reductions in fuel and electricity costs), making externally designed incentives function more readily. Through a randomized controlled trial in Bangladesh, Chakravorty et al. (2020) demonstrated that AWD leads to water saving and increased profits only in villages where hourly volumetric pricing has been introduced, with no

effect in villages with area-based fixed pricing (PW2)—that is, the "water saving equals cost saving" structure of pump-fed irrigation serves as a direct driver of AWD adoption.

Table 3. SWOT analysis of pump-fed irrigation.

	Positive Factors	Negative Factors
Internal Factors (structural characteristics of the irrigation system)	Strengths (PS1–PS2) - PS1: The authority over water management decisions belongs to individual farmers. - PS2: The locus of decision-making authority and the beneficiaries of promotion-scheme incentives coincide.	Weaknesses (PW1–PW2) - PW1: Because management is individual, collective action for wide-area, spatially comprehensive rollout is difficult to establish - PW2: Institutional instability of the volumetric pricing system (under fixed pricing, the effect of PS2 disappears)

Weaknesses

On the other hand, the weakness of pump-fed irrigation is that, because management is individual, wide-area, spatially comprehensive collective action is difficult to establish (PW1). This is in a mirror-image relationship with the strengths of gravity-fed irrigation (S1: wide-area decision-making function; S2: suitability for collective MRV).

3.3 Opportunities and Threats Common to Both Irrigation Types

Opportunities and Threats are the policy, market, and technological environment surrounding the irrigation system, and they are external factors that both gravity-fed and pump-fed types commonly face. In this study, they are organized as items common to both types.

Table 4. Opportunities and threats common to both irrigation types.

	Positive Factors	Negative Factors
External Factors (environment surrounding the irrigation system)	Opportunities (O1–O4) - O1: Development of PES schemes - O2: International tailwind for climate change mitigation - O3: Existence of established models of collective payment schemes, such as Japan's payment scheme for the multifunctional roles of agriculture - O4: Advances in wide-area monitoring technologies such as remote sensing and IoT sensors	Threats (T1–T2) - T1: Methods for quantitatively evaluating AWD effects at the collective level are not yet established - T2: Existence of policies that may act as headwinds against AWD implementation

Opportunities

As an opportunity, recently developing PES schemes can be cited first (O1): frameworks for environmental payments aimed at climate change mitigation are expanding nationally and internationally, establishing an institutional foundation for converting AWD-driven methane reductions into economic benefits. International policy tailwinds for climate change mitigation are also strengthening, such as the methane reduction targets under the Paris Agreement and the Global Methane Pledge (O2).

In addition, established institutional models support collective water management through fixed-rate grants to farmer organizations; Japan's payment scheme for the multifunctional roles of agriculture (O3) offers instructive insights for Southeast Asian countries that share the conditions of gravity-fed irrigation and collective management, as a reference model in which the collective is the payment recipient. Moreover, advances in remote sensing and IoT sensors are increasing the possibility of evaluating AWD effects on a wide-area basis (O4).

Threats

Among the threats, the first is that methods for quantitatively evaluating AWD effects at the collective level (methane reduction, water saved, etc.) are not yet established, constituting a barrier to operating schemes such as PES (T1): while measurement at individual fields has progressed at the research level, wide-area evaluation at the scale of the irrigation district has not been established. In addition, policies aimed at rural development and income improvement may, as a result, act as headwinds against AWD implementation (T2); the Philippines' irrigation water fee exemption (FISA) is one such example, eroding the incentive to save water.

3.4 Comparison between Irrigation Types

Contrasting the two irrigation types, the greatest difference is that the greatest strength of pump-fed irrigation—the coincidence of decision-making authority and incentive beneficiaries—is structurally absent in gravity-fed irrigation. This structural difference is the fundamental reason adoption does not progress in gravity-fed systems even when the type of economic incentive is changed. Conversely, the wide-area rollout that pump-fed irrigation struggles with is a domain gravity-fed irrigation can realize through its collective governance. The two thus occupy different strategic positions, requiring institutional designs that leverage each one's strengths. Based on this contrast, the TOWS analysis below centers on the elements judged to be inherent to gravity-fed irrigation and to have a large impact on AWD adoption (in particular W1 and W2, and their counterparts S1 and S2).

4. DISCUSSION

4.1 Strategy Derivation Through the TOWS Matrix

Table 5 presents the TOWS matrix constructed centered on the elements judged to be inherent to gravity-fed irrigation and to have a large impact on AWD adoption.

Table 5. TOWS matrix for gravity-fed irrigation.

	Opportunities (O)	Threats (T)
Strengths (S)	SO strategy Link collective governance (S1) and suitability for collective MRV (S2) to PES schemes (O1) and established models of collective payment schemes (O3) to build a PES-receiving scheme with water user organizations as the unit.	ST strategy Leverage collective governance (S1) to maintain and supplement collective water-saving incentives through water user organizations even under policies that may act as headwinds (T2).
Weaknesses (W)	WO strategy In response to the mismatch between governance and incentive beneficiaries (W2) and the weak economic motivation (W3), design PES (O1) as a collective payment to water user organizations.	WT strategy As a prerequisite for collective incentive design ($W2 \times O1$), undertake the establishment of methods for evaluating effects at the collective level (T1), which is indispensable.

As a **WO strategy**, in response to the most decisive weakness, W2 (the mismatch between the locus of decision-making authority and the beneficiaries of promotion-scheme incentives), leveraging opportunity O1 (the development of PES schemes) yields a direction for realizing incentive design targeting the collective: by designing PES revenues as collective payments to water user organizations, the locus of decision-making authority (collective) can be aligned with the beneficiaries

of incentives. The same logic addresses W3 (the fee structure in which water saving is unlikely to translate into economic benefits), with O1 creating economic motivation at the collective level.

As an **SO strategy**, a direction is derived that combines the collective governance structure (S1) and suitability for collective MRV (S2) possessed by gravity-fed irrigation with the development of PES schemes (O1) and the existence of institutional models in which the collective is the payment recipient (O3): building a PES-receiving scheme with water user organizations as the unit. In particular, S2, compared with the individual-farmer-based MRV of pump-fed irrigation, more readily allows economies of scale to operate, serving as a foundation that maximizes the opportunity of O1.

As an **ST strategy**, a direction is derived that leverages the collective governance structure (S1) possessed by gravity-fed irrigation as a buffer against policies that may act as headwinds to AWD implementation (T2). As exemplified by the Philippines' irrigation water fee exemption (FISA), fees and subsidies targeting individual farmers can unintentionally erode the incentive to save water; however, placing the recipient of incentives with water user organizations rather than individuals maintains collective water-saving incentives that are less susceptible to such individual-targeted measures. The ST strategy thus reinforces the collective-payment direction of the WO strategy from the perspective of robustness against external policy headwinds.

The **WT strategy** concerns the very foundation of AWD adoption in gravity-fed irrigation. The combination of the most important weakness, W2, and the most important threat, T1 (methods for evaluating effects at the collective level are not yet established), indicates that the establishment of methods for evaluating AWD effects at the collective level is a prerequisite for implementing collective incentive design through PES. The feasibility of the WO and SO strategies thus depends on overcoming this external threat.

4.2 Barriers to AWD Adoption in Gravity-Fed Irrigation

As a result of the SWOT–TOWS analysis in this study, it was systematically shown that the core of the barrier to AWD adoption in gravity-fed irrigation lies in the structural mismatch (W2) whereby decision-making authority rests with the collective (water user organization) while promotion-scheme incentives target individuals. This is a structural problem that cannot be overcome by changing the type of economic incentive. The case of VnSAT in Vietnam strongly supports this point, showing that even under the same project and the same scheme design (premium-rice sales revenue), the AWD adoption rate is substantially lower under the water management of cooperatives compared with individual operators (Ong et al., 2025).

Here, the asymmetry of the benefit structure raised in the introduction connects with this problem. Of the two effects of AWD, water saving is returned to the farmers themselves, whereas methane (GHG) reduction is a global public good scarcely returned to individual farmers. Because of this externality, farmers structurally lack the economic motivation to voluntarily implement AWD for GHG reduction. When such an externality exists, it is justified to internalize it through payment from the entities that enjoy the benefit to the entity that supplies it (Engel et al., 2008), and PES and carbon credits are precisely the institutional means of realizing this internalization.

Therefore, AWD adoption in gravity-fed irrigation calls for incentive design targeting the collective in a twofold sense. First, external payment (PES) is needed to internalize the externality of GHG reduction; and second, because decision-making authority rests with the collective in gravity-fed systems, that payment should be directed to the collective (the water user organization). The former is derived from the asymmetry of the benefit structure and the latter from the governance structure, and the overlap of the two justifies collective PES payment to the collective.

This direction of payment is also partially supported by prior cases. The conversion of AWD-driven methane reductions into carbon credits is already entering the implementation stage—for example, the Nalgonda Rice Farming project in India groups multiple farmers to generate credits—but such cases are based on distribution to individual farmers, which differs in design from the collective payment with

water user organizations as the unit that this study proposes. Japan's payment scheme for the multifunctional roles of agriculture, which supports collective water management activities through fixed-rate grants to farmer organizations, offers a closer reference model in which the collective is the payment recipient, though direct transplantation is difficult owing to differences in land ownership patterns and the history of farmer organizations.

4.3 Prerequisite for Overcoming the Barriers

An important implication revealed by the TOWS analysis in this study (the WT strategy) is that the feasibility of the WO and SO strategies described above functions on the prerequisite of establishing methods for evaluating AWD effects at the collective level. That is, the implementation of collective payment through PES requires that the environmental effects of AWD be quantitatively evaluated at the collective level and presented as the basis for payment, yet at present such evaluation methods remain at the individual-field level.

Here, it should be noted that certain feasibility challenges in implementing AWD under rotational irrigation have been pointed out in previous studies, such as the difficulty of synchronizing drying periods across fields (Samoy-Pascual et al., 2022). At the same time, because rotational irrigation is itself a water-saving distribution method adopted under water scarcity, farmers under it can be considered to have a high latent need for AWD, so it may also be regarded as an environment with latent groundwork for adoption.

What is important is that, even if such a feasibility barrier is overcome, the problem of the absence of collective incentives still remains. Even when AWD implementation becomes technically and operationally possible, adoption will not progress without economic motivation for the collective to implement and continue it—and to create that motivation through PES, making effects visible at the collective level is indispensable.

Therefore, in the social implementation of AWD in gravity-fed irrigation, collective incentive design and the establishment of evaluation methods are two requirements that are mutually complementary; however, the two are not in an equal, parallel relationship. Rather, the order is such that the establishment of evaluation methods functions as a prerequisite for institutional design. Unless the visualization of AWD effects at the collective level is achieved, collective incentive design through PES cannot reach the implementation stage. In this sense, the establishment of evaluation methods is positioned as a prerequisite for the social implementation of AWD.

CONCLUSION

Through a three-country comparison and SWOT–TOWS analysis, this study showed that the core of the barrier to AWD adoption in gravity-fed irrigation lies in the mismatch between the governance structure and the beneficiaries of promotion-scheme incentives. Overcoming this barrier requires incentive design targeting water management organizations: because the GHG-reduction effect of AWD is a global externality scarcely returned to individual farmers, external payment is justified, and because decision-making authority rests with the collective in gravity-fed systems, that payment should be designed as a collective payment to water user organizations through PES, thereby aligning decision-making authority with beneficiaries.

However, such collective incentive design requires, as a prerequisite, the establishment of methods for quantitatively evaluating the environmental effects of AWD at the scale of the irrigation district, since current individual-field-level measurement cannot present the basis for PES payment at the collective level. The social implementation of AWD must therefore proceed in two stages—the design of collective incentives and the visualization of effects at the collective level—with the latter functioning as a prerequisite for the former. The collective governance of gravity-fed irrigation is at once a weakness that limits individual farmers' discretion and a latent strength enabling wide-area AWD implementation; the key to realizing this potential lies in establishing technologies for visualizing effects at the collective level.

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