

RETHINKING IRRIGATION AND DRAINAGE MODERNIZATION FOR AGROECOLOGICAL TRANSITIONS UNDER CLIMATE CHANGE: LESSONS FROM LAO PDR

REPENSER LA MODERNISATION DE L'IRRIGATION ET DU DRAINAGE POUR LES TRANSITIONS AGROÉCOLOGIQUES FACE AU CHANGEMENT CLIMATIQUE : LEÇONS TIRÉS DE LA RDP DU LAOS

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ABSTRACT

Agroecology is increasingly promoted as a pathway toward more resilient and sustainable food systems, yet irrigation and drainage have rarely been treated as central to agroecological transition. This paper examines how the 13 HLPE agroecological principles can reshape irrigation modernization in Lao PDR, which has been central to rice self-sufficiency and rural development but now faces mounting technical, financial, institutional, and environmental challenges including water user groups (WUGs) not functioning effectively. The analysis shows that modernization should be understood not simply as infrastructure rehabilitation or expansion, but as a broader rethinking of how water is governed, delivered, and integrated into agroecosystems under climate change. This paper highlights, in Lao PDR, the need to distinguish between small, community-based upland systems and larger, pump-dependent lowland schemes, because they face different hydrological, economic, and governance challenges. Across both upland and lowland schemes, inadequate water management, associated with inadequate operation and maintenance remains a major cause of under-utilization and poor performance. In the upland schemes modernization depends on storage, watershed condition, and locally adapted management; in the lowland schemes, it depends more on improving pumping efficiency, financial viability, and ecological performance in larger canal systems. Reinterpreting irrigation through the HLPE principles shows that a more coherent modernization agenda must go beyond efficiency to include recycling, biodiversity, soil and water stewardship, diversification, participation, fairness, and stronger land and natural resource governance. The paper argues that irrigation and drainage are not peripheral to agroecological transition, but central to building climate resilience from productive and biodiverse landscapes, promoted by inclusive rural development in line with the current Lao PDR food system transformation and agroecology action plans.

Keywords: Agroecology; climate change; water user groups (WUGs); environmental challenges; climate resilience; canal systems.

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RESUME

L'agroécologie est de plus en plus présentée comme une voie vers des systèmes alimentaires plus résistants et durables, mais l'irrigation et le drainage ont rarement été considérés comme des éléments centraux de la transition agroécologique. Cet article examine la manière dont les 13 principes agroécologiques du HLPE peuvent redéfinir la modernisation de l'irrigation en République démocratique populaire du Laos, qui a joué un rôle central dans l'autosuffisance rizicole et le développement rural, mais qui aujourd'hui fait face à des défis techniques, financiers, institutionnels et environnementaux croissants, notamment le dysfonctionnement des groupes d'utilisateurs de l'eau (WUG). L'analyse montre que la modernisation ne doit pas être perçue uniquement comme la réhabilitation ou l'extension des infrastructures, mais comme une refonte plus large de la manière dont l'eau est gérée, distribuée et intégrée dans les agroécosystèmes dans le contexte du changement climatique. Cet article souligne que dans la RDP du Laos, la nécessité est ressentie de distinguer les petits systèmes communautaires des hautes terres des grands périmètres des basses terres dépendant du pompage, car ils sont confrontés à des défis hydrologiques, économiques et de gouvernance différents. Tant dans les systèmes d'irrigation de hautes terres et de basses terres, une gestion insuffisante de l'eau, associée à une exploitation et à un entretien inadéquats, reste une cause majeure de sous-utilisation et de mauvaises performances. Dans les systèmes de hautes terres, la modernisation dépend du stockage, de l'état des bassins versants et d'une gestion adaptée aux conditions locales; dans les systèmes de basses terres, elle dépend davantage de l'amélioration de l'efficacité du pompage, de la viabilité financière et des performances écologiques dans les grands systèmes de canaux. Une réinterprétation de l'irrigation à la lumière des principes du HLPE montre qu'un programme de modernisation plus cohérent doit aller au-delà de l'efficacité pour intégrer le recyclage, la biodiversité, la gestion responsable des sols et de l'eau, la diversification, la participation, l'équité ainsi qu'une gouvernance renforcée des terres et des ressources naturelles. Cet article soutient le fait que l'irrigation et le drainage ne sont pas des éléments périphériques de la transition agroécologique, mais qu'ils sont essentiels pour le renforcement de la résistance climatique grâce à des paysages productifs et riches en biodiversité, favorisés par un développement rural inclusif, conformément à la transformation actuelle du système alimentaire de la RDP du Laos et aux plans d'action en matière d'agroécologie.

Mots-clés : Agroécologie; Changement climatique; Groupes d'utilisateurs de l'eau (GUE); Défis environnementaux; Résistance climatique; Systèmes de canaux.

INTRODUCTION

Climate change, environmental degradation, and growing pressures on food and water systems are renewing interest in agroecology as a pathway to more resilient and sustainable agriculture. Agroecology is increasingly understood not merely as a set of practices, but as an approach to redesigning food systems by strengthening ecological processes, biodiversity, farmer agency, and social inclusion. To guide this transition, the High-Level Panel of Experts (HLPE) on Food Security and Nutrition identified 13 agroecological principles spanning biophysical dimensions - such as recycling, input reduction, soil health, biodiversity, and synergy - and social and institutional dimensions including co-creation of knowledge, fairness, participation, connectivity, and land and natural resource governance (HLPE, 2019). Yet water remains largely implicit within this framework, receiving only limited attention despite its central role in shaping ecological interactions, production choices, risk management, and rural livelihoods (Freed et al., 2025). Across the Mekong region, agroecological initiatives are increasingly demonstrating pathways toward more sustainable and resilient farming systems (Hett et al., 2023), but the role of irrigation and drainage within these transitions remains poorly understood.

Modernization of irrigation and drainage systems has typically focused on water control and crop production for rice monocultures. In much of Southeast Asia, this has encouraged centralized infrastructure and relatively rigid service regimes with limited attention to biodiversity, soil and water interactions, knowledge co-production, or participation. Under climate change, crop monocultures are becoming more vulnerable to droughts, floods, infrastructure deterioration, and intensifying competition among water users. These pressures make it necessary to rethink irrigation and drainage not simply as

functions of hydraulic infrastructure, but as socio-ecological processes embedded within watersheds, river basins, and food systems.

From this perspective, irrigation modernization should be assessed not only in terms of efficiency or production within command areas, but also in terms of how it contributes to a broader agroecological transition and climate resilience.

Lao PDR provides a particularly useful context for examining these issues. Irrigation has played a central role in rice self-sufficiency and rural development, but many schemes now face compound technical, financial, and institutional constraints that are intensifying as climate risks increase. Recent evidence points to the need for more integrated flood and drought management, better operations and maintenance, more efficient water use and enhanced community participation, reinforcing the relevance of irrigation modernization within wider climate adaptation and rural development agendas. At the same time, Lao PDR's irrigation sector is highly diverse, with small, community-based upland systems differing fundamentally from larger, pump-dependent lowland schemes in their hydrology, costs, ecological interactions, and governance requirements.

This paper argues that the 13 HLPE principles provide a useful framework for rethinking irrigation modernization in Lao PDR. Using evidence from an irrigation sub-sector review conducted in 2019 and subsequent interpretation through an agroecological lens, it examines how modernization pathways differ between upland and lowland systems and how future policy, investment, and research could better align irrigation and drainage with goals of resilience, diversification, ecological integrity, and inclusive rural development. The HLPE principles are used here not simply as normative ideals, but as an analytical framework for reassessing irrigation performance and identifying more coherent directions for modernization in the face of climate change.

METHOD

Sub-Sector Review

The data that this research is based upon was generated by an Irrigation Sub-sector Review conducted in 2018-2019 in Lao PDR, funded by the Asian Development Bank (ADB) (IWMI and WorldFish 2019), supplemented by an agroecological context assessment in Attapeu Province in 2023 (Clayton et al. 2023). The sub-sector review examined the technical, institutional, financial, and environmental factors influencing irrigation performance in Lao PDR and identified priorities for future sector investment. This paper reports the findings of that review and then reinterprets them in relation to the 13 agroecological principles (Wezel et al., 2020) as revised to integrate water and aquatic foods (Freed et al. 2025).

The original subsector review adopted a systems-oriented diagnostic approach that combined qualitative and quantitative methods, including document review, stakeholder consultation, irrigation data analysis, field visits, and regional validation workshops. A comprehensive literature review covered previous studies of irrigation performance, government reports, national statistics, and project documentation. Consultations were undertaken with key national stakeholders, including the Ministry of Agriculture and Forestry (MAF), Department of Irrigation (DOI), National Agriculture and Forestry Research Institute (NAFRI), Living Aquatic Resources Research Center, National Project Management Office (NPMO), Department of Livestock and Fisheries, the Asian Development Bank, and the World Bank. Discussions were also held with irrigation advisers, Provincial Agriculture and Forestry Offices (PAFO), District Agriculture and Forestry Offices (DAFO), Water User Groups (WUGs), and farmers, including both men and women. The review also analyzed data from the DOI database, including irrigated area in wet and dry seasons by province, irrigation system types in upland and lowland areas, and the operational performance of 2,438 WUGs in relation to operation and maintenance. Field visits were conducted to irrigation schemes in northern, central, and southern Lao PDR to assess performance under contrasting agroecological and institutional conditions. Stakeholder workshops and provincial feedback sessions were held in Luang Prabang, Vientiane, and Pakse to validate the findings and assess the relevance of recommendations across different regional contexts.

In a subsequent analytical step for this paper, the main findings and recommendations of the review were interpreted against the 13 HLPE principles to identify areas of convergence, reveal gaps, and reconsider irrigation modernization priorities in agroecological terms. This alignment was qualitative and thematic, with particular attention to ecological processes, diversification, knowledge co-production, participation, equity, and natural resource governance.

Irrigation in Lao PDR

Lao PDR remains a predominantly agrarian country in which irrigation plays an important role in agriculture, rural livelihoods, and national development. Economic growth in recent decades has been driven largely by natural resource exploitation, especially hydropower, mining, and timber, but agriculture continues to underpin livelihoods for much of the rural population. Almost all farmers (783,000 farming households) are still involved in rice production with 75% of arable land used for rice production (Figure 1). Rice accounts for a significant portion of the daily calorie and protein intake of rural people and rice consumption per capita is amongst the highest in the World (World Food Program, 2023). Rice yields have been steadily rising and now average around 4.2 tha^{-1} for the wet season, 5.0 tha^{-1} for the dry season and 2.0 tha^{-1} for upland, rainfed areas (IWMI/WorldFish 2019). Poverty and malnutrition remain significant, particularly in remote upland areas inhabited by ethnic communities, where weak infrastructure, limited market access, and harsh environmental conditions constrain development (World Bank, 2015).

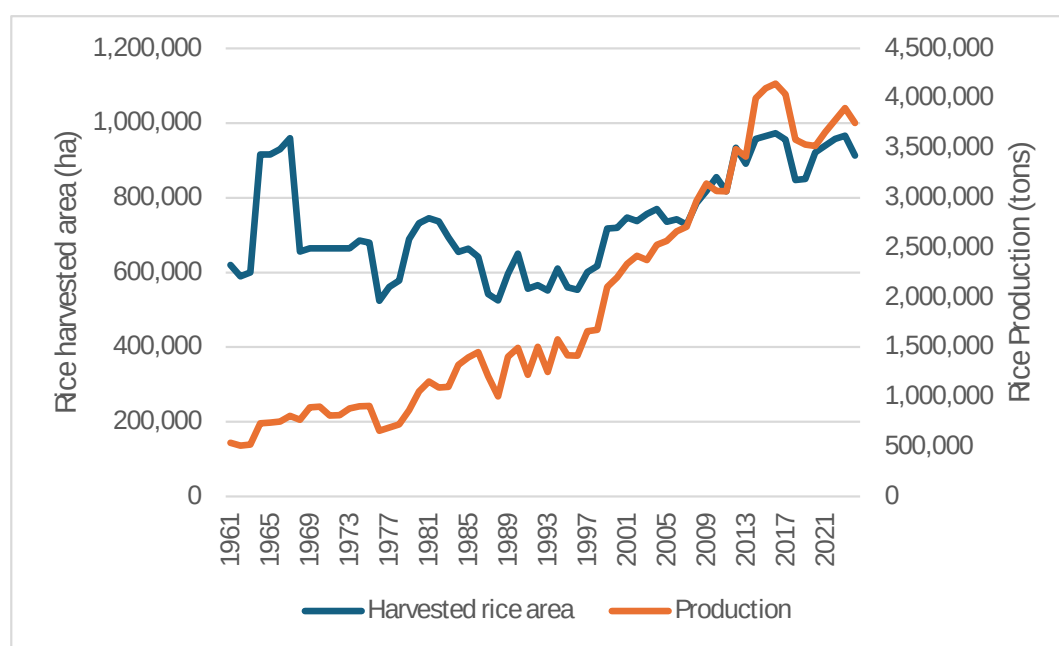


Figure 1. Evolution of Rice Production and Harvested Area
(Source: FAOSTAT <http://www.fao.org/faostat/en/#data/QC> (Accessed May 2026))

The broader policy environment has changed significantly since 2016. Earlier development strategies emphasized agricultural intensification, commercialization, and rice self-sufficiency, with irrigation expansion as a central instrument. More recent policies, particularly the 8th National Socio-Economic Development Plan (GoL, 2016a) as well as the national 2030 vision (GoL, 2016b) and 10-year Agricultural Development Strategy (GoL, 2010), place much greater emphasis on sustainability, green growth, resilience to natural disasters and climate change, nutrition-sensitive agriculture, and improved management of natural capital (World Bank, 2017).

These policy shifts have important implications for irrigation. The sector is no longer being judged only by the area served or its contribution to rice output; it is also expected to support cleaner and safer

agriculture, contribute to dietary improvement, and operate in ways that are environmentally sustainable and socially inclusive. As a result irrigation is perceived as a sector that helped Lao PDR achieve rice self-sufficiency in the past and must continue to do so but, at the same time, has to evolve if it is to remain relevant under a changing climate and development priorities.

RESULTS

Key findings from the Lao Irrigation Sub-Sector Review

Despite longstanding public investment, agriculture in Lao PDR remains largely rainfed. Nevertheless, irrigation plays a critical role in agricultural production, particularly of rice. Remote sensing and administrative data indicate that roughly three-quarters of cultivated land is rainfed and single-cropped, while the area receiving irrigation in the wet season is just over 314,000 hectares and dry-season irrigation is around 176,000-180,000 hectares. Considerable uncertainty remains because the national database is incomplete and inconsistent, and remotely sensed estimates suggest that total irrigated area may be somewhat higher than official records indicate.

A defining feature of irrigation in Lao PDR is the contrast between upland and lowland systems. Upland schemes are typically small, often between 10 and 100 hectares, and commonly gravity-fed using weirs or small diversions. Many have a long history of community ownership and management and, in some places, increasingly include technologies such as drip and trickle systems for horticulture, coffee, and fruit trees. Lowland systems, by contrast, tend to be larger and more capital intensive, often dependent on pumps drawing water from rivers and distributing it through canals over areas that can reach several thousand hectares. In uplands, weirs and pumped systems dominate dry-season irrigation, while in lowlands pumped systems are by far the dominant technology in both wet and dry seasons. These differences are not merely technical; they shape management needs, cost structures, and future development options.

The context in which irrigation operates is also being reshaped by broader changes in the rural economy. Basin water resource development, processes of rural transformation, climate change, and increasing environmental awareness are all contemporary drivers of change across agriculture and the irrigation sub-sector (Figure 2). Rice remains the dominant irrigated crop and is still critical for national food security, but returns to farmers are relatively low, especially in the dry season. High production costs, weak value chains, fragmented milling and aggregation systems, and poor incentives for quality all reduce farm-gate profitability.

At the same time, rural households are increasingly diversified, with many now earning substantial shares of income from off-farm sources. This affects irrigation in two ways: first, many farmers are reluctant to invest labor and money in dry-season rice when water supplies are uncertain and returns are modest; second, where markets are accessible, farmers are increasingly interested in higher-value crops such as vegetables, fruit, coffee, maize, and industrial crops. Informal, farmer-led irrigation outside public command areas is expanding in both uplands and lowlands, showing that farmers are willing to invest in irrigation when it gives them greater control over water and better economic returns.

The principal challenges facing irrigation in Lao PDR are operational, financial, and institutional. Many schemes are underutilized and underperforming because infrastructure is deteriorating, operation and maintenance are inadequate, and water delivery is unreliable. In lowland pumped systems, irrigation service fee collection rarely covers the cost of electricity, routine maintenance, and repairs, and many schemes have accumulated large debts to the national electricity company, Electricite du Laos. In both upland and lowland areas, poor maintenance means canals silt up, pumps break down, and command areas shrink over time. Across the country, many irrigation systems exist in a cycle of construction, deterioration, emergency repair, and rehabilitation because maintenance is not planned systematically and public budget allocations for upkeep are irregular. These problems are reinforced by weak local governance. WUGs were intended to increase farmer ownership and take responsibility for operation and maintenance, but most are not functioning effectively, especially in larger lowland schemes where technical complexity and financial demands exceed local capacity. Low profitability of rice, unreliable

service, and the burden of electricity payments create a vicious cycle in which poor performance reduces willingness to pay, and low collection of irrigation service fees further reduces performance.

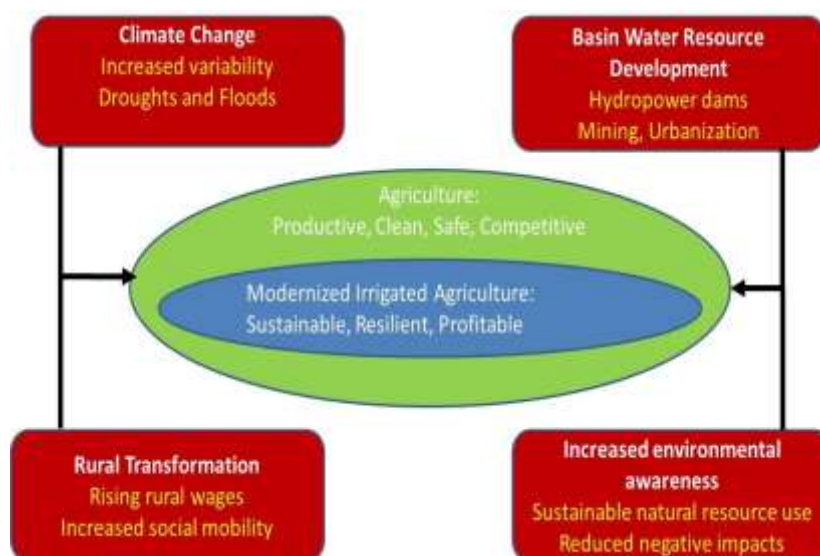


Figure 2. Drivers of Change Influencing the Irrigation Sector in Lao PDR
(source: IWMI and WorldFish, 2019)

Hydrological and environmental pressures make these management problems even more severe. In upland systems, limited dry-season flows and insufficient storage are increasingly aggravated by watershed degradation, including erosion, deforestation, and poor land management. Across the country, floods and droughts are recurrent hazards that cause major losses in agriculture and frequently damage irrigation infrastructure. Flood events in 2006, 2007, 2011, 2013, and 2018 caused substantial destruction, and climate projections indicate that both droughts and intense rainfall are likely to become more frequent and severe. Irrigation is also often planned in isolation from other water users, especially hydropower, even though dam operations can both exacerbate flood risks in some circumstances and create opportunities for more reliable dry-season flows. Environmental impacts extend beyond water quantity. Irrigation infrastructure can block fish migration and damage capture fisheries (Duncan et al, 2021), while growing use of agrochemicals poses risks to water quality, aquatic ecosystems, and human health (Freed et al., 2020). This is especially important in Lao PDR because rice-field fisheries and aquatic foods remain significant sources of nutrition and rural income.

Overall, irrigation in Lao PDR sits at the intersection of ambitious development goals and difficult structural constraints. It remains central to agricultural policy and rural development, but operates in a context of uneven economic transformation, persistent rural poverty, low returns from rice-based systems, fragmented markets, weak institutions, environmental degradation, and rising climate risk.

DISCUSSION

The future of irrigation in Lao PDR depends less on continued infrastructure expansion than on a more differentiated process of modernization. Many of the sector's weaknesses reflect systems designed for simplified rice production that are poorly matched to the ecological, social, and economic conditions now shaping rural change and climate risk. In this context, the 13 HLPE principles provide a useful framework for identifying modernization pathways that differ between upland and lowland systems. Rather than treating irrigation solely as water delivery, the principles draw attention to how irrigation and drainage can strengthen ecological interactions, enable diversified production, improve resource efficiency, and reinforce farmer agency and collective management under contrasting agroecological and institutional

conditions (Table 1). Distinguishing between upland and lowland irrigation systems is essential because the technical options, cost structures, ecological interactions, and governance requirements differ between them.

Better information is foundational to agroecological transition, but the knowledge requirements of modernization differ across system types. In upland areas, where schemes are small, diverse, and embedded in local ecological conditions, stronger information systems need to build on farmer knowledge of water sources, seasonal variability, and catchment dynamics. In lowland areas, the priority is more systematic data on scheme performance, pumping costs, fee collection, water delivery, and environmental effects across larger public systems. Strengthening databases, monitoring protocols, digital data collection, and performance benchmarking is directly linked to agroecological principles of *co-creation of knowledge*, *participation*, and *land and natural resource governance*. Recent introduction of solar pumps in Attapeu Province has shown promising results (Douangsavanh et al., 2025). Environmentally, it helped farmers manage climate variability and grow crops during dry periods; socially, it improved water access for households and farming, reduced the burden on women and children, and strengthened community cooperation; economically and nutritionally, it lowered costs by removing electricity expenses and enabled year-round vegetable farming, which improved food security and livelihoods. If farmers, WUGs, local agencies, and basin authorities jointly generate and interpret information, irrigation management can move from reactive administration toward more adaptive and accountable governance. In Attapeu Province the creation of WUGs, along with rules, monitoring tools, and hydrological studies, supported better protection of wetlands and the wider landscape (Douangsavanh et al., 2025). These efforts improved understanding of water flow and provided useful insights for future wetland water use regulations, while the monitoring system could help prevent long-term negative impacts from groundwater over extraction.

The long-standing neglect of operation and maintenance is not simply a technical failure but a systemic problem of financing, incentives, and institutional design, and it takes different forms in upland and lowland systems. In uplands, the main issues often concern maintenance of weirs, small diversions, local storage, and distribution structures under conditions of limited cash resources and strong dependence on watershed condition. In lowlands, the challenge is more strongly tied to the recurrent costs of pumping, electricity debt, deterioration of canal networks, and weak fee collection within larger command areas. Reframed against the HLPE principles, sustainable irrigation should reduce waste and unnecessary dependence on costly external resources by strengthening *recycling* and *input reduction*, while improving service models in ways consistent with *fairness* and *economic diversification*. Tailored financing and more viable service arrangements are therefore central to modernization, not only for financial sustainability but because they create the conditions for farmers to invest in more diversified and higher-value production.

Greater flexibility in water delivery is needed if irrigation is to support more diverse and profitable production systems, although the priorities differ between uplands and lowlands. In upland systems, modernization may involve small-scale storage, improved gravity control, pressurized distribution, and localized scheduling to support horticulture, agroforestry, and mixed farming under variable terrain and limited water availability (Wangpakapattanawong et al., 2017). In lowland systems, the priority is to move beyond rigid service regimes designed for rice monoculture by enabling more flexible water control, drainage, and scheduling that support crop diversification, rice–fish systems, and mixed farming at scale. Because many lowland rice-growing soils in Lao PDR are sandy and lack a laterite layer, improving soil moisture retention through practices such as mulching, reduced straw burning, integration of crops and livestock, and retention of trees within agricultural landscapes is particularly important (Rodenburg et al., 2022). Many of these practices build on farmers' existing knowledge and water management strategies. Together, they reflect the HLPE principles of *biodiversity*, *synergy*, *soil health*, *animal health*, *economic diversification*, and *social values* and *diets*. Evidence from global rice systems shows that diversification can simultaneously improve productivity, resilience, and environmental performance, demonstrating that more diverse rice-based systems can generate economic and ecological benefits rather than trade-offs (He et al., 2023). This strengthens the case for irrigation modernization that supports diversified production systems rather than optimizing water delivery solely for rice monoculture.

Table 1. Agroecology principles (HLPE 2019) and relationship to Irrigation Modernization

HLPE principle	Relevance to irrigation modernization	Upland Systems	Lowland Systems
Recycling	Improve the cycling of water, nutrients, sediments, and biomass within irrigated landscapes.	Link small diversions, soil and water conservation, on-farm storage, and reuse of organic matter to make limited dry-season flows more productive	Reuse of drainage water, better sediment and nutrient management in canal networks, and closer integration of paddy fields, ponds, and aquatic resources.
Input reduction	Reduce dependence on costly external inputs, energy, and repeated emergency repair through better design and asset management.	Improve diversion structures, storage, and distribution so gravity systems remain reliable with minimal fuel use.	Reduce pumping costs, electricity demand, leakage, and breakdowns in larger pump-canal systems
Soil health and water resources ¹	Support water control that protects soil structure, organic matter, and long-term productivity and ensure adequate quantity and quality of water for both in situ food production and downstream biodiversity and ecosystem services	Reduce erosion, improve infiltration, and integrate irrigation with slope and catchment management.	Improve water-level control, drainage, sedimentation, and soil fertility in paddy-based systems.
Animal health	Account for livestock, fisheries, and other integrated production systems rather than focusing only on crops.	Ensure reliable water access for small livestock and mixed farms	Support rice–fish systems, ponds, and aquatic habitats that support nutrition and income; Maintain fish habitat and connectivity across floodplains and within irrigation systems.
Biodiversity	Create conditions for more diverse crops, aquatic habitats, and greater ecological resilience.	Support horticulture, agroforestry, and crop mosaics adapted to variable terrain and water supply.	Move beyond rigid rice monoculture toward diversified rotations and canal-floodplain management that maintains ecological functions.
Synergy	Strengthen positive interactions among crops, water, soils, trees, fish, and livestock rather than managing them separately.	Link irrigation to watershed protection, tree crops, and soil conservation.	Coordinate canals, drainage systems, paddy fields, fisheries, and floodplain functions. Enhance synergies with other sectors (e.g. energy)
Economic diversification	Provide water services that enable more profitable and diversified livelihoods rather than locking farmers into low-return dry-season rice.	Enable horticulture, fruit trees, coffee, and other higher-value crops requiring reliable local water control.	Support crop diversification, staggered planting, and mixed farming through more flexible water delivery systems, including conjunctive use.
Co-creation of knowledge	Promote joint learning among farmers, agencies, and researchers rather than imposing uniform technical models..	Build on local ecological knowledge and community experience in managing small, diverse systems.	Adapt larger and more standardized schemes to local farming strategies, financial realities, and market conditions.

Social values and diets	Support food systems that are culturally appropriate, nutritious, and more diverse than staple grain production alone.	Strengthen vegetables, fruit, and mixed farming important to local diets and livelihoods.	Support more varied production while protecting aquatic foods associated with paddy landscapes.
Fairness	Improve equity in access to water, benefits, costs, and decision-making.	Address community rights, upstream–downstream sharing, and inclusion of poorer or remote users.	Improve equity in head-tail water allocation, fee structures, and maintenance responsibilities.
Connectivity	Strengthen links among producers, markets, consumers, and institutions so that irrigation services align with livelihood opportunities.	Link dispersed producers to extension, inputs, and markets that justify higher-value irrigation.	Improve coordination among scheme managers, farmer groups, traders, processors, and basin-level institutions.
Land and natural resource governance	Coordinate irrigation with catchment management, fisheries, wetlands, hydropower, and wider basin governance.	Integrate irrigation with forest management, erosion control, and dry-season flow regulation in small watersheds.	Coordinate irrigation with river regulation, floodplain management, fisheries, hydropower, and other major water users.
Participation	Increase the meaningful involvement of farmers and local actors in planning, operation, adaptation, and oversight.	Build on established traditions of community management.	Strengthen institutional mechanisms for participation in larger, more complex schemes where technology and finances exceed the capacity of farmer participation alone.

¹ This is a modified version of the HLPE principle as suggested by Freed et al. (2025) to make consideration of water in the principles more explicit

The scope of irrigation modernization must also be situated within integrated water resources management, watershed protection, and environmental stewardship, but the relevant scales differ between uplands and lowlands. In upland areas, irrigation performance depends heavily on forest cover, erosion control, and dry-season flow regulation within small watersheds. In lowland areas, it is shaped more by river regulation, floodplain dynamics, hydropower operations, fisheries, and competition with other major water users. This is where the HLPE principles of *synergy*, *soil health*, *biodiversity*, *animal health*, and *land and natural resource governance* become especially important. A genuinely modern irrigation agenda must therefore protect catchments, reduce sedimentation, integrate wetlands and floodplains where appropriate, and account for fisheries, aquaculture, and water quality in infrastructure design and operation. Modernization should be understood not as a self-contained irrigation intervention, but as part of wider landscape and basin governance.

Institutional reform is another central dimension of the modernization challenge. WUGs are vital, but they cannot be expected to carry the full burden of irrigation management under current conditions. From an agroecology perspective, reform should advance fairness, participation, connectivity, land and natural resource governance, and social values and diets. This implies governance arrangements in which farmer organizations remain central but are supported by stronger public institutions, clearer accountability of public institutions, and more differentiated service models suited to scheme size and complexity. It also implies recognizing local cultural practices, gendered roles, and community priorities in the way irrigation services are planned and delivered. Stronger connections between irrigation agencies, producer groups, markets, and consumers can help ensure that irrigation supports not only production but also more localized value chains and food systems that are socially inclusive and responsive to changing dietary demand.

Seasonality is a critical but often overlooked dimension of irrigation modernization. The large difference between wet-season and dry-season irrigated area in Lao PDR reflects not only water availability constraints but also changing livelihoods, labor availability, production risks, and the low profitability of dry-season rice. Increasingly, irrigation is valued as much for reducing climate risk and stabilizing production as for expanding dry-season cultivation. From an agroecological perspective, modernization should therefore prioritize flexible water services that support diverse seasonal strategies, including supplementary irrigation, diversified cropping, livestock and fisheries integration, and targeted dry-season production where economically and environmentally viable. In uplands, this may involve strategic use of limited water for high-value crops supported by local storage and watershed management; in lowlands, it may involve balancing supplementary irrigation for wet-season rice with opportunities for diversified dry-season production. Recognizing seasonality as a defining feature of agroecosystems, rather than a constraint to overcome, is consistent with the HLPE principles of biodiversity, economic diversification, and synergy.

In lowland areas, irrigation performance is increasingly influenced by hydropower development and reservoir operations. While hydropower can enhance water availability and reduce drought risk, altered flow regimes, sediment trapping, reduced floodplain connectivity, and weak coordination between energy and irrigation sectors can undermine the ecological functions and water delivery services on which irrigated agriculture depends. In some areas, uncontrolled or poorly coordinated reservoir releases during the rainy season inundate agricultural land, causing crop losses. Such releases can also disrupt planting calendars and increase production risks for downstream communities. Modernization therefore requires stronger integration of irrigation planning with basin governance, reservoir operation, fisheries management, and floodplain conservation, consistent with the HLPE principles of synergy, biodiversity, recycling, and land and natural resource governance.

Irrigation operations research remains essential because modernization in Lao PDR needs to be treated as an iterative learning process. This is fully consistent with the HLPE principles of *co-creation of knowledge* and *participation*, but it also points to the need to operationalize all 13 principles together rather than selectively. Key unresolved questions include which technologies are most appropriate under different agroecological conditions, how asset management should function in flood-prone systems, what business models can sustain service delivery, and how fisheries, livestock, and diversified cropping can be integrated into irrigation design. These issues suggest the need for piloting, comparative evaluation, and adaptive management. More broadly, irrigation modernization in Lao PDR should be understood as a pathway toward agroecological transition: one that improves efficiency and resilience while also strengthening equity, ecological integrity, local knowledge, and farmer agency.

CONCLUSION

Irrigation modernization in Lao PDR could be more effectively formulated, not as a narrow process of rehabilitating infrastructure or expanding command areas typical of top-down direction from a water engineering perspective, but rather as a broader transition in how water is governed, delivered, and integrated into agroecosystems under climate change. The evidence gathered through the sub-sector review and considered here shows that the sector's current constraints are not only technical; they are rooted in weak data, underfunded operation and maintenance, limited institutional capacity, environmental degradation, and business models that are poorly aligned with the realities of contemporary rural livelihoods. These challenges are expressed differently in upland and lowland systems. In uplands, modernization needs to work with small-scale, community-based and watershed-dependent irrigation where local ecological knowledge, storage, and catchment condition are decisive. In lowlands, the priority is to improve the performance, financial viability, and ecological functioning of larger pump and canal systems historically oriented toward rice monoculture. Treating these systems through a single modernization model is unlikely to be effective.

Using the HLPE principles as an analytical framework highlights that a more coherent modernization agenda must go beyond efficiency to encompass recycling, biodiversity, soil and water stewardship, diversification, fairness, participation, and stronger land and natural resource governance. In practical

terms, this means designing irrigation systems that support more flexible and diverse production, strengthen ecological interactions across farms, watersheds, and floodplains, and create governance arrangements in which farmers, public agencies, and other water users can adaptively manage risk and opportunity. In this sense, in Lao PDR irrigation and drainage are not peripheral to agroecological transition; they are central to it. If future policy, research, and investment are aligned with this broader perspective, irrigation in Lao PDR can contribute not only to more reliable production, but also to climate resilience, healthier landscapes, and more inclusive rural development.

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