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Short-Term Resilience vs. Long-Term Sustainability: Asia's Two Irrigation Models

How groundwater transformed South Asia's rice resilience while surface-water irrigation underpins Southeast Asia's long-term water security

Executive Summary

Asia has developed two distinct irrigation pathways that have fundamentally transformed rice production. South Asia's groundwater-led irrigation model has largely decoupled rice production from monsoon variability, delivering exceptional short-term production resilience but creating growing concerns over groundwater depletion. In contrast, Southeast Asia's surface-water irrigation model, built around reservoirs and canal systems, offers greater long-term water sustainability, but remains more vulnerable to droughts and El Niño-induced water shortages.

The future of Asian food security lies not in choosing between these two approaches but in integrating their strengths. Renewable surface water should remain the primary source of irrigation wherever feasible, while strategically managed groundwater should provide flexibility during climate shocks. In regions where sustainable surface-water expansion is not possible, governments should promote crop diversification away from groundwater-intensive rice through appropriate incentives and market support. This integrated irrigation model can simultaneously enhance climate resilience, protect water resources, and sustain Asia's rice production over the long term.

Introduction

Asia's rice economy has quietly undergone one of the most important structural transformations in modern agriculture. Across much of the continent, irrigation has largely replaced rainfall as the principal determinant of rice production. Yet this transformation followed two very different pathways. South Asia relied primarily on groundwater, while Southeast Asia invested in surface-water infrastructure. These contrasting pathways have created two distinct forms of climate resilience that will shape the future of Asian food security.

Asia's two irrigation models evolved under different hydrological and institutional conditions. South Asia's groundwater revolution created exceptional short-term production resilience, while Southeast Asia's investments in surface-water infrastructure laid the foundation for long-term water sustainability. Understanding these contrasting irrigation pathways has become increasingly important because South and Southeast Asia together account for more than half of global rice production and consumption, making the region central to global food security. In the face of climate change, the future of Asian food security depends on integrating both into irrigation systems that are resilient to seasonal shocks while protecting water resources for future generations.

Asia's Two Irrigation Models

Asia's two largest rice-producing regions followed fundamentally different pathways in developing irrigation systems. These contrasting models were not the result of different policy objectives but of different hydrological endowments, institutional capacities, and economic realities.

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South Asia's Groundwater Revolution: Fast Track to Food Security

The irrigation strategies of two of the largest rice producers in the sub-continent, i.e., India and Bangladesh, evolved during the Green Revolution when food security was the sub-continent's overriding national priority. Although the region invested heavily in major dams and canal systems, extending surface-water irrigation across its vast and geographically diverse agricultural landscape required enormous public investment and decades of construction. Many productive farming regions lay beyond the command areas of major canals, while most rivers exhibit highly seasonal flows associated with the southwest monsoon. Supported by free power and subsidized tube wells and submersible pumps, millions of farmers invested in tube wells and bore wells. Irrigation expansion became largely farmer-driven rather than government-driven. Unlike canal irrigation, groundwater enabled farmers to decide when to plant and irrigate without waiting for canal releases or monsoon rainfall.

In India, nearly 70% of the paddy area was irrigated in 2023-24¹, with groundwater accounting for about 65% of the irrigated area². Similarly, approximately 55% of Bangladesh's rice area was irrigated in 2022-23³, with nearly 79% of the irrigated area supplied by groundwater through shallow and deep tube wells³. The remaining 21% was irrigated using power pumps, some of which also extract groundwater. Together, India and Bangladesh illustrate the groundwater-led irrigation model that has evolved across much of South Asia. Pakistan has also followed a broadly similar groundwater-led trajectory. These figures demonstrate that groundwater has become the dominant source of irrigation across much of South Asia, providing farmers with the flexibility to maintain rice production despite increasing variability in monsoon rainfall.

This decentralized model dramatically accelerated irrigation expansion and transformed South Asia's agricultural economy. Rice production became increasingly independent of seasonal rainfall, allowing farmers to maintain production even during delayed monsoons. The rapid growth in irrigation contributed to higher yields, greater cropping intensity, increased farm incomes, and ultimately transformed India into the world's largest rice exporter. However, this remarkable success has created a new challenge. The rapid expansion of solar-powered irrigation is adding a new dimension to groundwater management. By reducing the cost of pumping to nearly zero, solar energy can encourage greater groundwater extraction where effective regulation and water-use incentives are absent. While solar irrigation contributes to climate mitigation by replacing diesel pumps, it should be accompanied by policies that promote groundwater recharge, conjunctive water use, and sustainable pumping practices. The region's future challenge is no longer expanding irrigation but managing groundwater sustainably while preserving the production resilience it has created.

Southeast Asia's Surface-Water Model: Sustaining Long-Term Water Security

Southeast Asia followed a different development pathway. Countries such as Vietnam, Indonesia, and the Philippines possess extensive river systems, fertile delta regions, and favorable topography for gravity-fed irrigation. Governments therefore concentrated investment in reservoirs, diversion structures, and canal networks supplied by renewable river flows rather than promoting widespread groundwater development. Unlike South Asia, irrigation expansion remained largely a public-sector undertaking, supported by long-term investments in reservoirs, river diversions, and gravity-fed canal systems.

Although this approach required greater public investment and considerably longer implementation periods, it created irrigation systems built primarily on renewable surface-water resources. Surface-water irrigation offers important long-term advantages. Rivers and reservoirs are replenished annually through the hydrological cycle, reducing dependence on finite groundwater reserves. Gravity-fed irrigation also requires considerably less energy than groundwater pumping while enabling coordinated water allocation across large irrigation systems.

In the Philippines, approximately 71% of the paddy area was irrigated in 2025⁴, but unlike South Asia, more than 90% of the irrigated area relied on surface water⁵. Indonesia also depends predominantly on surface-water irrigation. Approximately 65% of its rice area is irrigated⁶, with surface water accounting for nearly 99% of irrigated rice acreage⁷.

¹Agricultural Statistics at a Glance, 2024-25, Ministry of Agriculture and Farmers Welfare, Govt. of India (https://agriwelfare.gov.in/en/Agricultural_Statistics_at_a_Glance).

²<https://www.ndtv.com/india-news/pm-launches-rs-6-000-crore-national-groundwater-management-plan-on-atal-bihari-vajpayees-birth-anniv-2154120>.

³Yearbook of Agricultural Statistics-2025, Bangladesh Bureau of Statistics, Govt. of Bangladesh (<https://bbs.gov.bd/pages/static-pages/6922e0d6933eb65569e28cbf>).

⁴Open Database, Philippine Statistics Authority (<https://openstat.psa.gov.ph/>).

⁵FAO AQUASTAT Philippine Country Profile (<https://www.fao.org/aquastat/en/geospatial-information/global-maps-irrigated-areas/irrigation-by-country/country/PHL>) & Philippine Statistics Authority Census of Agriculture (https://psa.gov.ph/system/files/main-publication/ais_agri_struct_resources2017.pdf)

⁶BRIS Agricultural Research Platform (https://icar.org.in/sites/default/files/Circulars/Indonesia_BRICS_Agriculture_Report.pdf).

⁷FAO AQUASTAT Indonesia Country Profile

Vietnam represents the most extensive surface-water irrigation system in the region. More than 90% of its rice area is irrigated, with virtually all irrigation supplied by surface water through an extensive network of rivers, reservoirs, and canals⁸.

Nevertheless, reliance on surface water also creates vulnerabilities. During strong El Niño events, reduced rainfall lowers reservoir storage and river discharge, limiting irrigation supplies and delaying planting. Unlike farmers in India, many Southeast Asian farmers cannot easily compensate for reduced canal water through groundwater pumping. As a result, rice production remains more closely linked to seasonal climate variability.

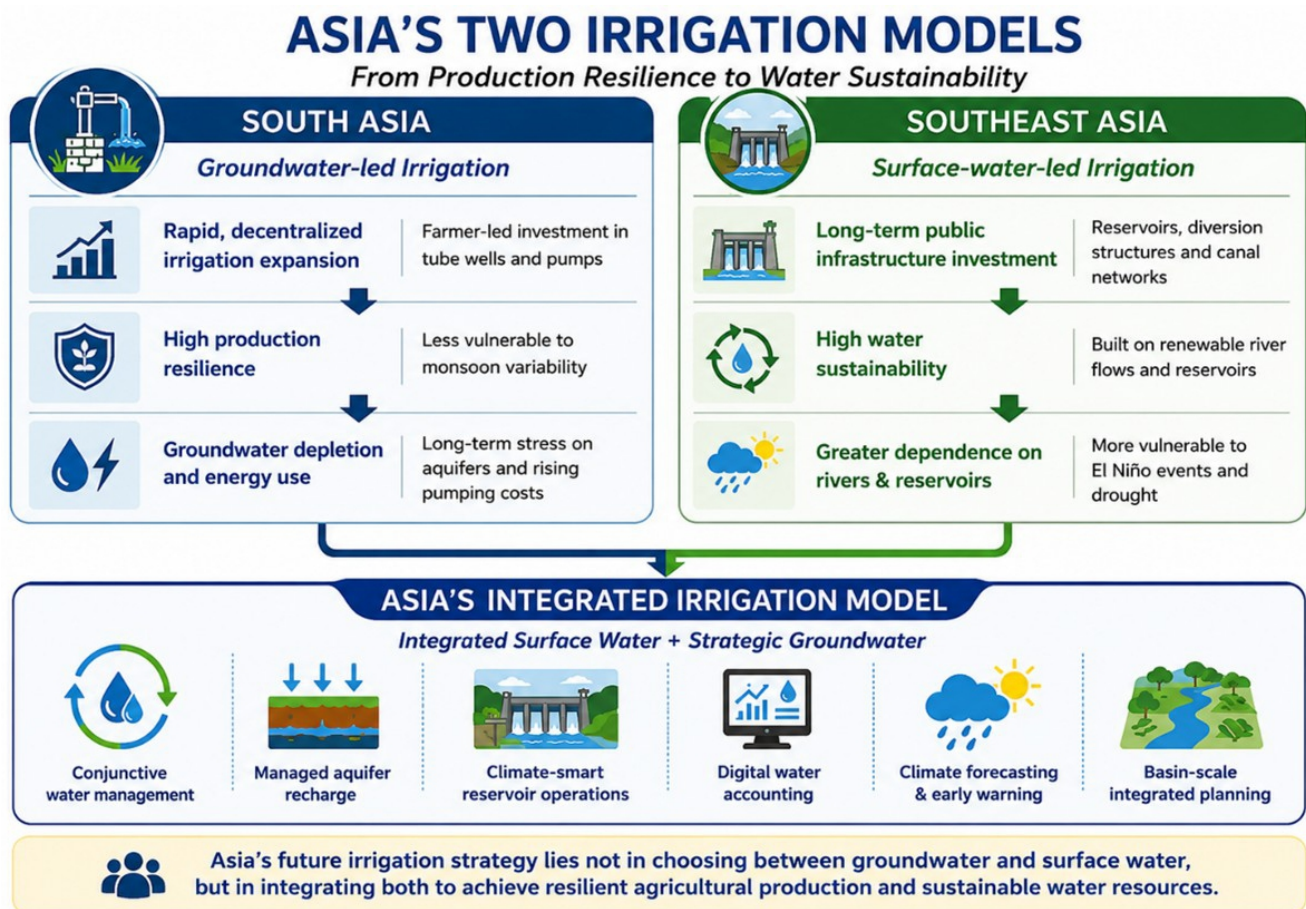
Short-Term Resilience vs. Long-Term Sustainability

The comparison between South Asia's groundwater-led irrigation system and Southeast Asia's surface-water model reveals an important insight. Irrigation systems should be evaluated not only by their ability to protect agricultural production during seasonal weather shocks but also by their capacity to sustain water resources over the long term.

South Asia's Groundwater: South Asia's groundwater revolution demonstrates how decentralized irrigation can dramatically reduce production risks associated with delayed monsoons and erratic rainfall. Farmers can respond immediately to rainfall deficits by pumping groundwater, allowing planting schedules and crop management decisions to remain largely unaffected by temporary weather disruptions. This flexibility has fundamentally changed the relationship between monsoon rainfall and rice production. In many irrigated regions, rainfall deficits no longer translate directly into lower production.

Southeast Asia's Surface-water: Southeast Asia presents the opposite situation. Because irrigation depends predominantly on rivers, reservoirs, and gravity-fed canal systems, groundwater resources generally remain under less pressure. This provides a stronger foundation for long-term water security and environmental sustainability. At the same time, dependence on seasonal river flows means that agricultural production remains more vulnerable to droughts and El Niño events that reduce reservoir storage and river discharge.

The two irrigation systems therefore optimize different dimensions of resilience. South Asia has largely reduced seasonal production risk through groundwater-led irrigation whereas Southeast Asia has largely protected the long-term sustainability of its water resources. The challenge under climate change is that future irrigation systems must achieve both.



⁸Tuan, C.M., L. J. Young, T. K. S. Rate. 2022. *Impact of Irrigation System Improvement on Rice Production in Vietnam. Proceedings of the 4th International Conference on Business, Economics & Finance* (file:///C:/Users/smoha/Downloads/ProceedingsOfFourthICBEF-2022-Hue7-trang-2.pdf)

Toward Asia's Integrated Irrigation Model

South and Southeast Asia have each developed successful irrigation systems suited to their respective natural resource endowments and historical development priorities. The next generation of irrigation policy should combine the flexibility of groundwater with the sustainability of surface-water systems through integrated water resources management.

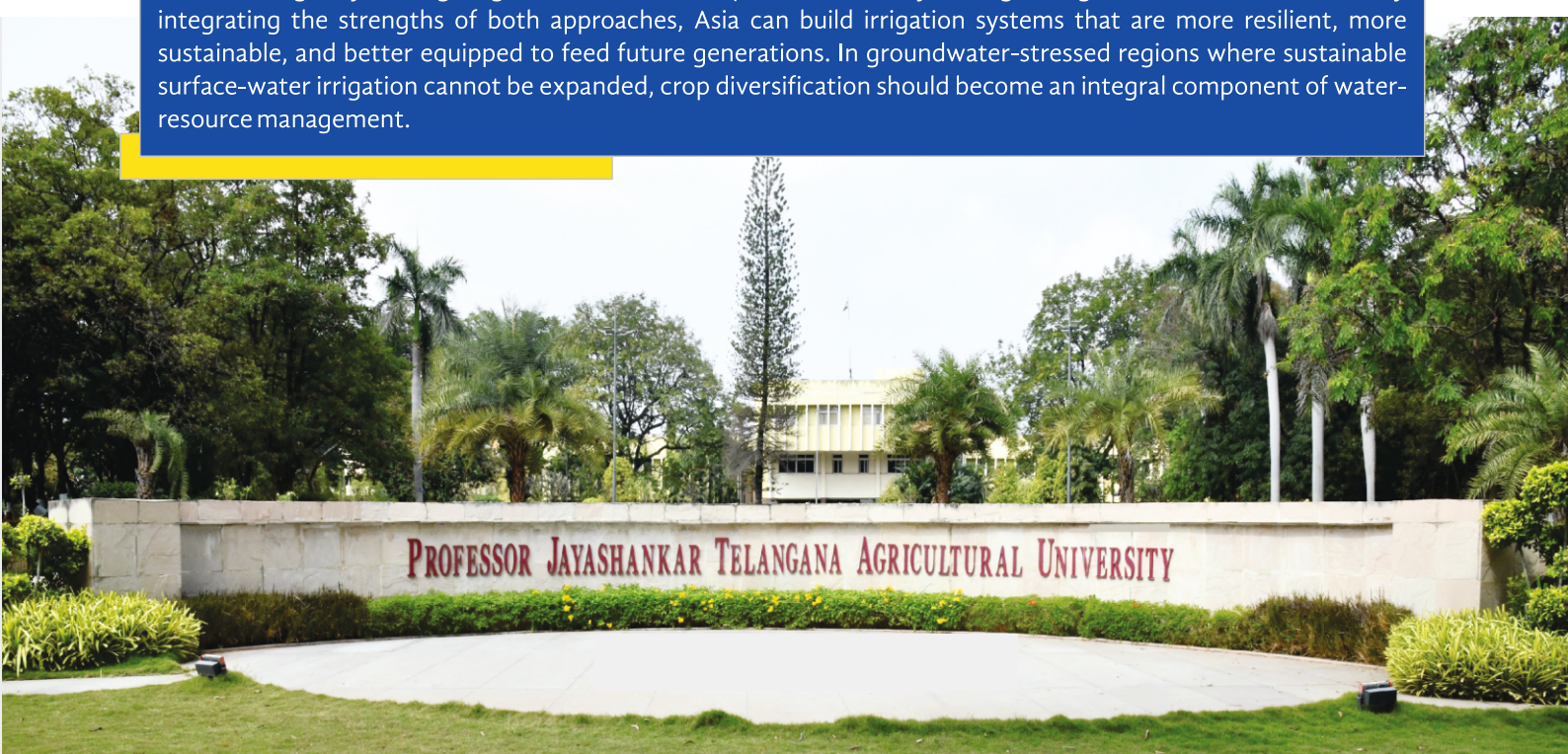
This integrated model should combine renewable surface-water infrastructure as the primary source of irrigation with strategically managed groundwater, a supplemental source during droughts and other periods of water stress. The future of Asian agriculture will depend not on choosing between groundwater and surface-water, but on managing both resources as complementary components of a single, climate-resilient irrigation system. Southeast Asia may be better positioned to develop an integrated irrigation model because it already possesses extensive investments in reservoirs, canals, and river-basin infrastructure. By strategically expanding groundwater as a supplemental source during droughts, the region can strengthen climate resilience without fundamentally altering its reliance on renewable surface-water resources. South Asia, by contrast, faces the more complex task of rebalancing a groundwater-dependent irrigation system while preserving the production resilience that has underpinned regional food security.

Where hydrological constraints limit the expansion of renewable surface-water irrigation, continued dependence on groundwater-intensive rice cultivation may not be sustainable over the long term. In such areas, governments should encourage a gradual transition toward more water-efficient cropping systems while protecting farm incomes through market incentives, risk management, and investments in alternative value chains.

Concluding Remarks

South and Southeast Asia have developed two highly successful but fundamentally different irrigation systems in response to their unique hydrological conditions, development priorities, and institutional capacities. South Asia's groundwater-led model has delivered remarkable production resilience by largely decoupling rice production from seasonal monsoon variability. Southeast Asia's surface-water model, built on decades of investment in reservoirs and canal networks, has created irrigation systems that are inherently more sustainable over the long term.

Climate change is redefining the future of irrigation across Asia. The challenge is no longer simply expanding irrigation coverage, but designing systems that simultaneously strengthen food security and protect water resources. Renewable surface-water infrastructure should remain the foundation of irrigation wherever feasible, while strategically managed groundwater should provide flexibility during droughts and climate shocks. By integrating the strengths of both approaches, Asia can build irrigation systems that are more resilient, more sustainable, and better equipped to feed future generations. In groundwater-stressed regions where sustainable surface-water irrigation cannot be expanded, crop diversification should become an integral component of water-resource management.



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