

INNOVATING AGROECOLOGY-BASED INDIGENOUS TECHNOLOGIES FOR CLIMATE-RESILIENT WATER MANAGEMENT

INNOVATION DES TECHNOLOGIES AUTOCHTONES FONDÉES SUR L'AGROÉCOLOGIE POUR UNE GESTION DE L'EAU RÉSISTANTE AU CHANGEMENT CLIMATIQUE

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ABSTRACT

Declining water availability is a major consequence of climate change, posing significant challenges for contemporary water management. In response, there is growing recognition of Indigenous water management technologies and knowledge systems (ITK), developed over generations by mountain communities to cope with spatial and temporal variability in water availability driven by complex physiographic conditions. Rooted in a deep understanding of local ecological systems, these technologies promote sustainable resource management and offer valuable nature-based solutions to climate change. However, despite increasing calls to upscale ITK concepts, systematic research and practical efforts for their adaptation and integration remain limited.

This paper examines two such Indigenous technologies: the *Karez* system—gently sloping underground tunnels used to access groundwater in Central Asia—and gravity canal-based daily flow-regulating ponds in the trans-Himalayan region. It first analyzes the scientific principles underlying their functioning and then, through case studies in Nepal, evaluates the transferability and effectiveness of their core concepts for climate-resilient water infrastructure and management. The paper suggests that the technological concepts underlying these Indigenous technologies, when adequately understood and contextually adapted, can be successfully integrated into modern engineering design of water infrastructure to enhance climate resilience in water management.

Keywords: Water management, agroecology, Indigenous technology, Climate adaptation, Mountainous landscape, and Nepal.

RESUME

La diminution des ressources en eau est une conséquence majeure du changement climatique, qui pose des défis considérables à la gestion contemporaine de l'eau. En réponse à cela, on tend de plus en plus à reconnaître la nécessité des technologies et des systèmes de connaissances autochtones (ITK) en matière de gestion de l'eau, développés au fil des générations par les communautés montagnardes pour faire face à la variabilité spatiale et temporelle de la disponibilité en eau, induite par des conditions physiographiques complexes. Ancrées dans une compréhension profonde des systèmes écologiques locaux, ces technologies encouragent une gestion durable des ressources et offrent de précieuses solutions fondées sur la nature pour lutter contre le changement climatique. Cependant, En dépit des appels croissants font en faveur d'une mise à l'échelle des concepts ITK, il existe peu de recherche systématique et des efforts concrets visant à leur adaptation et à leur intégration. Cet article analyse deux de ces technologies autochtones : le système Karez — des tunnels souterrains à pente douce utilisés pour accéder aux eaux souterraines en Asie centrale — et les bassins de réglage du débit

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quotidien alimentés par des canaux gravitaires dans la région transhimalayenne. Il analyse tout d'abord les principes scientifiques qui mettent l'accent sur leur fonctionnement, puis, à travers des études de cas menées au Népal, évalue le transfèrement et l'efficacité de leurs concepts de base des infrastructures et une gestion de l'eau résistantes au changement climatique.

Cet article précise que les concepts technologiques associés à ces technologies autochtones, lorsqu'ils sont correctement compris et adaptés au contexte, peuvent être intégrés avec succès dans la conception technique moderne des infrastructures hydrauliques afin de renforcer la résistance au climat dans la gestion de l'eau.

Mots-clés : Gestion de l'eau; Agroécologie; Technologie autochtone; Adaptation au climat; Paysage montagneux; Népal.

INTRODUCTION

Mountain communities in many countries depend on farming for their livelihoods. Water is a critical resource, yet the region's steep physiography and sharp altitudinal variation create significant spatial and temporal variability in water availability. In response, communities have developed diverse indigenous water management technologies and practices over generations, shaped by local resource endowments, engineering and ecological principles, and societal requirements. Many of these systems remain in use.

Despite their benefits, systematic recognition of indigenous technologies and knowledge (ITK) has emerged only recently, driven by growing water insecurity and climate change. Their strong grounding in local agroecological systems makes them effective for sustainable management and relevant to current challenges. Many international initiatives advocate scaling up such technologies, yet research and implementation remain limited.

Existing studies have largely focused on infrastructural layout, functionality, and governance, with limited attention to the scientific principles underlying these systems, which are key to assessing their broader applicability.

Against this backdrop, this paper examines two indigenous technologies: the *Karez* of Central Asia and the gravity canal-based daily flow-regulating pond (DFRP) in trans-Himalayan Nepal. It analyzes their scientific principles and evaluates the transferability of their concepts to address contemporary water challenges. Case studies illustrate how these concepts have been adapted to modern contexts, including climate-related impacts. The paper argues that, if properly understood, these technological principles can be integrated into modern engineering design for sustainable water management.

Objectives

The objectives of this paper are twofold. First, to document the scientific principles underlying the functioning of these technologies. Second, to examine and document, through real-time case studies, the effectiveness, adoptability, and scalability of their concepts to address contemporary water challenges.

MATERIALS AND METHODS

The study draws on multiple field-based studies (Parajuli and Sharma 2000, Parajuli et al 2001, Pradhan et al 2017, Goes et al 2017) complemented by recent case studies from Nepal. It also includes an extensive review of literature, including policy documents, along with key informant interviews with national and international experts. Additionally, it builds on the authors' long-term field observations and professional experience in water management across Nepal and other Asian countries.

UNDERSTANDING THE TERMS: INDIGENOUS, TRADITIONAL, AND TECHNOLOGY

Indigenous and traditional

The terms indigenous and traditional are often used interchangeably but differ in meaning. Indigenous refers to the local initiative, though it may incorporate external elements and is therefore dynamic and evolving. Traditional, by contrast, refers to old and may not be locally originated.

Technology

Technology, in water management, refers to a system of material objects that transform water through processes governed by scientific principles. When developed using local knowledge, these are termed indigenous technologies. The water management technologies examined in this paper are outlined below.

Ponds

Ponds are natural or artificial depressions used to store water for multiple purposes, also referred to as tanks or reservoirs depending on capacity. Their role in water harvesting across hills and valleys is well documented (Felices et al 2020, Agrawal et al 2023, Mishra and Gurung 2023, and Khawas et al 2026). However, their function as flow-regulating systems remains underexplored. From this perspective, this paper classifies ponds into three categories.

- **Seasonal flow-regulating pond:** These are typically large ponds or reservoirs, including wetlands. Their primary function is to regulate inflow/outflow to ensure water availability throughout the year.
- **Occasional flow-regulating pond:** These are small ponds with occasional inflow and outflow, fed by rainfall within micro-watersheds, wastewater from community taps, or both. Increasingly common in the mid-hills, they have emerged as an adaptive response to critical winter and summer dry spells. They typically support kitchen gardens and nearby fields.
- **Daily flow-regulating pond (DFRP):** These are small ponds that store water from a gravity canal with a small or variable flow throughout the day (daily) and release it over a few hours as a pulse delivery. Their storage capacity is determined by the volume of daily inflow. The pond described in this paper is the daily flow regulating pond (DFRP)

Karez: Karez is an ancient groundwater harvesting system found mostly in central Asia. It acquires water from the groundwater aquifer and transports it to the open surface through a gently sloping underground tunnel.

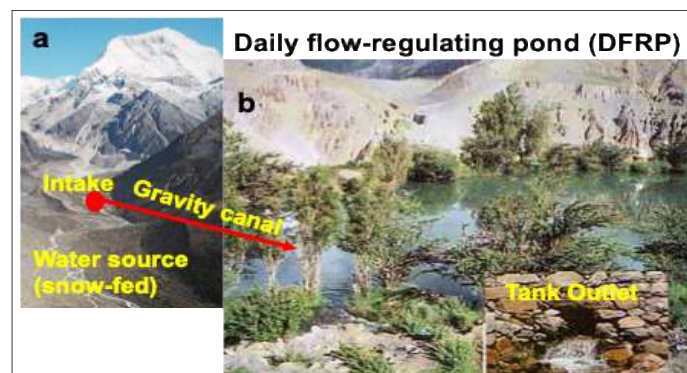


Figure 1. Typical gravity canal and DFRP of an indigenous water harvesting system

INDIGENOUS WATER MANAGEMENT TECHNOLOGIES AND INNOVATING THEIR CONCEPTS

Daily flow regulating pond (DFRP) in the trans Himalayan region

The Trans-Himalayan region, located north of the high Himalayas in the Hindu Kush Himalayan belt, lies in a rain shadow and forms a cold, arid landscape at elevations of 2,900 - 6,000 m. Agriculture here depends entirely on irrigation.

Snow and glaciers are the sources of water, which melt in the upper reaches of the watershed and flow downhill in the form of a stream (Figure 1a). The run-of-the-river type of canals fed by such a snow-fed stream first supplies water to a daily flow-regulating pond (DFRP) (Figure 1b). The DFRP then serves multiple uses: domestic needs (excluding drinking), livestock, irrigation, and watermills, in that order of priority. The system operates year-round except during winter freezing.

A DFRP is a small storage structure that collects canal flows through the day, mainly overnight, and releases them during the day as pulse water delivery. In Nepal, such ponds are locally known as ching (Parajuli and Sharma 2000), while they are known as zing in Ladakh, India (D'souza 1997). Figure 1b presents a ching.

Hydrological function of DFRP

Although not commonly found in the mid-hills, a DFRP is an important flow-regulating infrastructure in the trans-Himalayan region. This is because of the flow characteristics of a snow-fed stream. As snow and glaciers start melting slowly in the morning and faster through the day till late afternoon, the flow available in a snow-fed stream and corresponding canals increases considerably in the evening compared to that in the morning.

The evening flow in such a canal usually remains 4-5 times more than the morning flow. This variability makes direct water use difficult, mainly in maintaining equitable irrigation services. Thus, a DFRP accumulates the gradually varying incoming flows over a period, mainly at night, and releases a steady uniform flow for a defined period. In this sense, a DFRP converts the gradually varying inflow to a steady and uniform outflow (Figure 2).

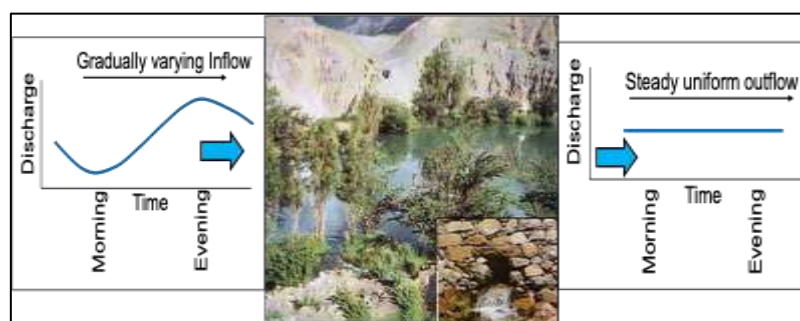


Figure 2. Hydrological function of DFRP, a conceptual sketch

Adapting DFRP for climate-resilient irrigation in the mid-hills.

Declining water availability due to climate change has reduced the resilience of community-managed irrigation systems in Nepal's mid-hills, which were originally built to irrigate monsoon paddy. As a result, many such small systems cannot irrigate dry-season crops. The reasons are twofold. First, canals designed for large monsoon flows are inefficient in conveying small dry season flows. Second, even when conveyed, flows at the farm level often become non-usable (termed non-modular flow), as such

flow, when applied to a field, does not advance for irrigation. In such a situation, introducing DFRP in these canals can address this challenge. A case study presented below explains this argument.

Case study (Thado Kulo Irrigation System): The Thado Kulo Irrigation System in the Syangja District irrigates 5.3 ha of land using water from a small perennial stream nearby through a 700 m earthen canal. Although this system continued to irrigate the monsoon paddy, it could not irrigate the winter and spring crops as the available flow reduced to about 0.8 lps. To address this issue, farmers constructed two ponds (68,000 and 87,000 liters) at different elevations, fed by separate canals, but from the same source. These ponds fill in 18–24 hours and release stored water over 2–2.5 hours the next day, irrigating about 0.25 ha per cycle. This daily operation provides two irrigations for winter crops and pre-sowing irrigation for spring crops.

This case demonstrates how the DFRP concept -originating in the Trans-Himalayan region - can be adapted to store small flows over a period and release them as usable pulses for a short period, enabling efficient irrigation under water-scarce conditions. Figure 3 presents a DFRP in the mid-hills with a conceptual hydrological function.

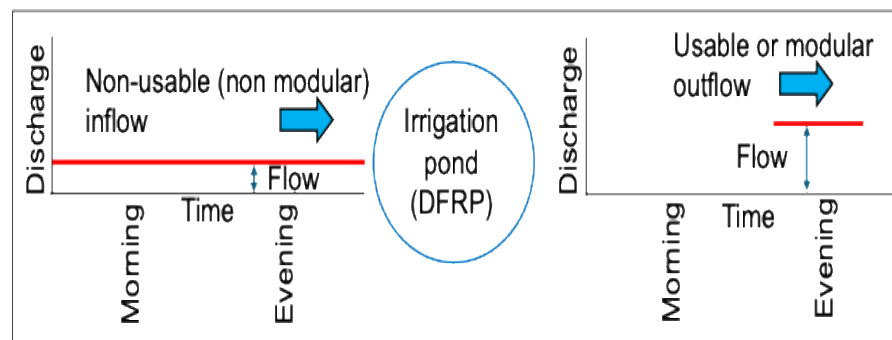


Figure 3. DFRP in mid-hills with conceptual hydrological function

Karez - a groundwater harvesting system in central Asia

Karez is an underground tunnel that acquires water from an aquifer and transports it to the open surface (Figure 4a). It is an ancient system, widely regarded as a global human heritage (Abudu et al 2019). Its length may vary from a few hundred meters to several kilometers, with discharge varying between 30 and over 200 lps. Mott Macdonald (2013) provides the basic physical attributes of *Karez*s in Helmand Province, Afghanistan.

Wilkinson et al (2012) noted that at around 1000 BC, the area in the Persian Empire suffered from declining precipitation, resulting in the reduction of spring discharge. As a result, villagers started excavating the land surface following the “spring-line” with a view to getting more water, which in turn created a *Karez*. This hypothesis suggests that a *Karez* emerged as a response to reduced spring flows. Over time, they spread to several countries and are known as *Qanat* in Iran and *Karez* in Afghanistan and Pakistan.

Hydrological function of Karez

Functioning of a *Karez* is shaped by the balance between water extractions from the shallow groundwater aquifer and its recharge, which in turn is shaped by the precipitation in the area, landscape, and geology. Its development begins with digging a “mother well” 2–5 m below the groundwater level to physically assess aquifer conditions and potential groundwater yield (Goes et al 2017). The well is then deepened to allow an initial intersection of the tunnel section with a water-bearing aquifer for about 200 m (McClymonds 1972). A horizontal tunnel (Figure 4c) with a series of vertical adits (Figure 4b) is constructed to convey water by gravity. These adits provide ventilation and allow the removal of excavated material.

As Karez systems draw water from shallow aquifers, many of them are drying (Ahmad et al 2004, Wessels 2005). A recent study found that over half of the Karez systems in Afghanistan had dried, while discharge from functioning systems had declined sharply (Mott MacDonald 2013). One major cause was the increasing use of gasoline-powered tubewells since 1990, which intensified groundwater extraction and created a negative water balance.

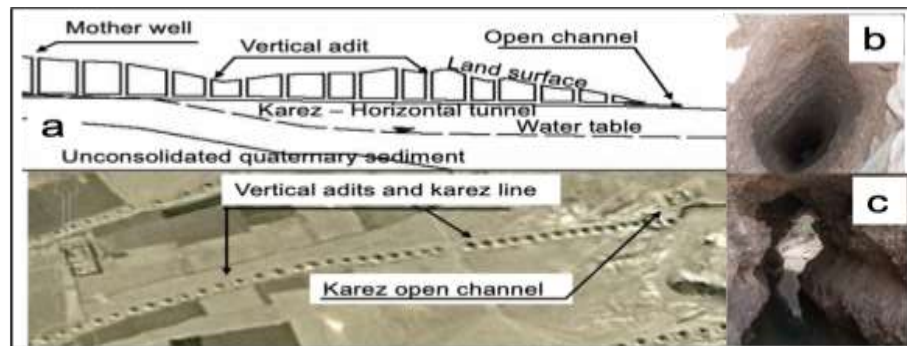


Figure 4. Schematic of Karez and its adits in Google Map

Innovating the Karez concept to revive dried springs

Drying springs in mountains due to climate change and other human activities are a major water challenge affecting rural livelihoods. To address this situation, and drawing on the hydrological function of a Karez, an attempt was made to revive a dried spring in Mainapokhari, Nepal, by drilling a horizontal borehole. The section below presents the case study.

Horizontal Springwell in Mainapokhari:

Mainapokhari village (Baitheshwor Rural Municipality, Dolakha District) had several springs, including a main spring emerging from a fractured rock outcrop. After the 2015 earthquake, this spring—which had flowed for generations—completely dried up (Figure 6a). The area lies in the southern Mahabharat hills at about 2,300 m elevation (27°38'37.10" N, 86°10'27.04" E).

The earthquake may have deformed the local geology by shifting rock layers and creating new fractures, altering spring-flow paths. As a result, the spring flow pathway that has been feeding the main spring since time immemorial could have been redirected through new rock fractures. This change may have caused the main spring to dry up. Figure 5 presents the conceptual sketch of the spring flow path and groundwater flow of the area after the earthquake.

After the main spring dried up, the local community requested external support for its revival. In response, the Government of Nepal, conducted detailed hydrogeological and geophysical investigations, including Electrical Resistivity Tomography (ERT), in 2017. As the focus of the study was to identify the saturated zone in the vicinity of pre-existing spring aquifer areas, the resistivity values and hydrogeological information of the area were further analyzed using the ERT, rock joint mapping, and other related data. This analysis led to the assessment and identification of key saturated zones therein, which in turn established the feasibility of spring restoration.

Based on these findings, three horizontal boreholes were drilled, spaced 2–3 m apart horizontally and 5–10 cm vertically (Figure 6b). Each borehole was 30 m long with a gentle gradient of 5%. Core drilling was used, and casing pipes supported unstable sections, which were later replaced with polyethylene pipe, with thin, long grooves cut out at its top and sides, especially along the saturated and partially saturated formation, to let water flow in. This intervention certainly demonstrates a practical, Karez-inspired approach to reviving dried springs in mountain regions. Where feasible, this approach can be used and scaled up to revive dried springs in the mountains by continuing the aquifer recharge program.

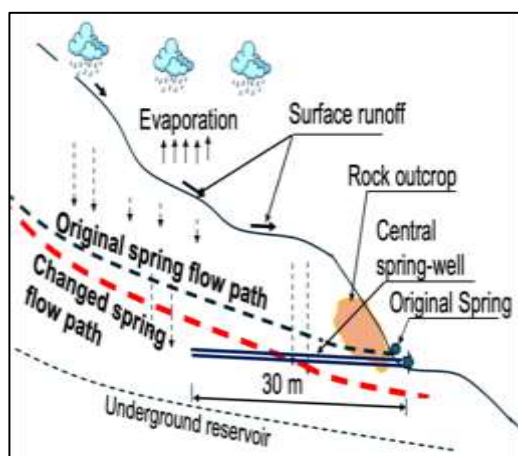


Figure 5. Conceptual sketch, displaced spring



Figure 6. Post-earthquake spring-wells

DISCUSSIONS

Given the focus of this paper, the following sections examine the effectiveness of the daily flow regulating pond, followed by the horizontal Springwell, a Karez-inspired technological innovation, for climate-resilient water management. A brief conclusion follows.

Most mid-Daily flow regulating pond for climate-resilient irrigation

hill irrigation systems in Nepal were designed to supplement monsoon paddy, ensuring timely transplantation and bridging rainfall gaps. Dry-season irrigation was treated as a secondary, mainly from a technological perspective. As paddy requires three to four times more water than dry-season crops, systems were built with larger canal capacities, leaving small tributaries and local water sources untapped, as they were considered too small for the paddy-based irrigation systems.

While these systems once supported livelihoods, paddy farming has become economically marginal due to cheaper imported rice enabled by road access in most mid-hill areas. In addition, unreliable dry-season supply, and declining precipitation with longer dry spells have contributed to agricultural decline and increased migration.

Yet there is strong potential for agricultural intensification and commercialization through dry season high-value crops for local and export markets. This context calls for a shift in irrigation thinking toward technologies suited for dry-season irrigation needs (Figure 7).

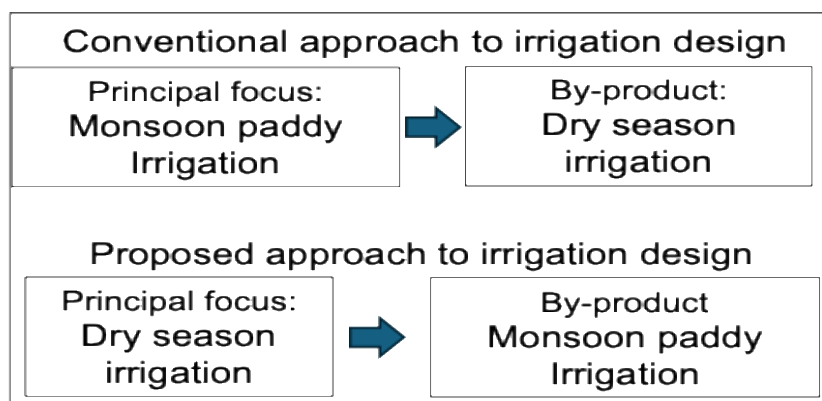


Figure 7. Suggested shift in irrigation thinking

This paper suggests that the daily flow regulating pond is one such option, requiring smaller system capacity and lower capital investment, while enabling use of local water sources that were left behind by the paddy-based irrigation systems. However, as irrigation is an input to profitable agriculture - not an end in itself - policies should promote “agriculture-led irrigation development.” This does not imply abandoning monsoon paddy cultivation. It should continue for local consumption and export, as it is preferred for its flavor and contributes to water conservation and downstream base flows for dry season use (Parajuli 2026).

Horizontal Springwell for climate-resilient Springwater management

Springs are part of groundwater systems, where infiltrated water is stored within geological formations. Their storage capacity depends on precipitation, geology, topography, and land use/land cover. Water stored in these aquifers feeds springs. However, the hydrology of springs, in terms of their occurrence and flow dynamics, remains poorly understood due to limited studies (Bricker et al 2014, Shrestha et al 2018). Likewise, the impacts of climate change and anthropogenic activities on spring hydrology remain unclear. In addition, as these aspects are highly site-specific, their generalization is difficult.

In Nepal's mid-hills, declining spring flow and groundwater resources are driven by climate change, human activities, and the region's geology. The area consists of fractured metamorphic and sedimentary rocks that form aquifers. Springs typically emerge along fault lines, joints, and lithological contacts.

Climate change has disrupted recharge mechanisms through erratic monsoon rainfall, prolonged dry spells, and rising temperatures, which increase evapotranspiration and reduce soil moisture. As a result, aquifers receive less replenishment, leading to declining spring discharge and falling groundwater. Human activities - including deforestation, road construction, urban expansion, and unplanned land use further damage recharge zones and subsurface flow paths. Studies show that 16–30% of springs in Nepal have dried up (Poudel and Duex 2016, Shrestha et al 2018, WBG 2022, and ICIMOD 2022), nearly 60% show declining discharge, and semi-urban springs have experienced a 72% flow reduction over the past decade (Chauhan et al 2023).

The above situation demands immediate action to revive dried springs, which are the lifeline of many hill communities. One existing approach is spring-shed management (Shrestha et al 2018, ICIMOD 2022). Although sustainable, it is often time-consuming. In this context, where feasible, this paper suggests an infrastructure-led solution - a horizontal Springwell - inspired by the technological concept of *Karez*. Such systems can provide rapid spring revival, while spring-shed management can ensure long-term sustainability. It is cost-effective as it flows under gravity without requiring any energy for pumping. This approach not only helps revive the dried springs but also helps explain in understanding the phenomenon of spring hydrology in the given geological context.

Technologically, Springwell and *Karez* share similar principles: both acquire groundwater from aquifers and convey it to the surface through enclosed conduits by gravity. Their functioning depends on the balance between groundwater extraction and recharge. However, the main differences lie in groundwater assessment and construction methods. The advancement in modern tools and techniques made these changes possible. In Nepal, horizontal boreholes of over 60 m have already been drilled in mountainous terrain. In this context, horizontal Springwell may be regarded as a technological innovation for reviving dried springs.

CONCLUSIONS

Declining water availability is a major consequence of climate change, posing significant water management challenges. This paper examined two Indigenous technologies – the daily flow-regulating pond and *Karez* - to assess how their concepts can inform modern climate-resilient water infrastructure. The paper draws the following technology-specific conclusions:

A DFRP, which operates with small and localized water sources often overlooked by the paddy-based monsoon irrigation systems in the past, is a climate-resilient technology for agricultural transformation and commercialization, especially for dry-season irrigation. Similarly, the development of Springwell should be considered an immediate response to livelihood impacts caused by dried springs, followed by spring-shed conservation for its sustainability.

Finally, the paper concludes that the concepts underlying these Indigenous technologies, when innovated to local contexts, can be integrated into modern water infrastructure design to enhance climate resilience.

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