WATER KNOWLEDGE NOTE

Mitigating Floods for Managing Droughts through Aquifer Storage

An Examination of Two Complementary Approaches

Paul Pavelic[1]

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Interventions that are robust, cost effective, and scalable are in critical demand throughout South Asia to offset growing water scarcity and avert increasingly frequent water-related disasters. This case study presents two complementary forms of intervention that transform water hazards (floodwater) into a resource (groundwater) to boost agricultural productivity and enhance livelihoods. The first intervention, holiya, is simple and operated by individual farmers at the plot/farm scale to control local flooding in semiarid climates. The second is the underground transfer of floods for irrigation (UTFI) and operates at the village scale to offset seasonal floods from upstream in humid climates. Rapid assessments indicate that holiyas have been established at more than 300 sites across two districts in North Gujarat since the 1990s, extending the crop growing season and improving water quality. UTFI knowledge and experience has grown rapidly since implementation of a pilot trial in western Uttar Pradesh in 2015 and is now embedded within government programs with commitments for modest scaling up. Both approaches can help farmers redress the multiple impacts associated with floods, droughts, and groundwater overexploitation at a range of scales from farm plot to the river basin. The potential for wider uptake across South Asia depends on setting up demonstration sites beyond India and overcoming gaps in technical knowledge and institutional capacity.

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WORLD BANK GROUP

Problem Statement and Case Study Contribution

The South Asia region covers only about 3 percent of the world's land surface area but supports approximately 24 percent of the world's population. Despite steady progress in agriculture and rural development, poverty and food insecurity are endemic across much of the region. South Asia is also one of the most water-stressed regions of the world. According to the AQUASTAT database of the United Nations Food and Agriculture Organization, the average water endowment for 2013–17 is only 1,100 cubic meters per capita per year (cubic meters per person per year)—well below the corresponding statistic for Sub-Saharan Africa of 3,900 cubic meters per person per year. South Asia is also a region of immense contrast in water resources, with Bhutan most endowed at an impressive 101,000 cubic meters per person per year and the Maldives least endowed at only 80 cubic meters per person per year (for the same five-year period). Water resources management is challenged by the inherent variability in rainfall, which, together with the high level of water demand, brings recurring droughts that severely undermine progress toward Sustainable Development Goals for the region.

The highly seasonal, monsoonal-driven rainfall patterns that characterize the region lead to regular flooding. The region has an extensive history of devastating floods driven by high seasonal rainfall or major storm events. Areas badly affected by seasonal flooding are the downstream reaches of the Ganges basin in eastern India and western Bangladesh and along the length of the Indus floodplain in Pakistan. During the dry season, the same areas face critical water shortages when poor monsoons result in drought.

The average combined cost of floods in Bangladesh, India, and Nepal is estimated at US$1.53 billion per year, affecting 31 million people from 1971 to 2008 (World Bank 2010). The corresponding figures for drought are US$62 million per year and 26 million people impacted. The costs of groundwater overexploitation in the region do not appear to have been estimated, but the value of the groundwater economy for the agricultural sector alone in the three countries was estimated at US$10 billion per year about a decade ago (Shah 2007).

There is already clear evidence of climate change in the region, and it is likely to become more pronounced in coming decades (IPCC 2014; Sharma et al. 2010). Perhaps most significantly, the intensity and duration of rainfall will continue to change, altering the hydrologic cycle, exacerbating extremes in water variability, and leading to more floods and droughts with associated impacts on farmers. In addition, accelerated melting of Himalayan snow and ice may create conditions for more-frequent, higher-magnitude floods in the upper reaches of the receiving river basins (Sharma and de Condappa 2013). The consequences of climate change are extreme and complex across the region, and most of the rural population depends on agriculture, most of which is rainfed and heavily dependent on monsoons. Communities are affected differently by climate variability and climate change according to social structures associated with class, caste, ethnicity, and gender (Sugden et al. 2014).

Farmers rely on groundwater from the highly productive alluvial aquifers of the Indo-Gangetic Plain and from the hard rock aquifers that underlie much of peninsular India as a drought adaptation measure. Year-round reliance on groundwater for agricultural production has led to significant overexploitation. India's 2013 national groundwater resource assessment revealed that a high proportion of administrative blocks are classified as overexploited, and the situation continues to deteriorate (GoI 2017). Similar trends are also emerging more widely across the region (Qureshi et al. 2010; Saha et al. 2016).

South Asia, and India in particular, has rich experience in managed aquifer recharge (MAR) to harvest runoff waters and store the water underground, thanks to watershed development projects and programs by government and nongovernmental organizations (NGOs) (Sakthivadivel 2007). States such as Gujarat, Maharashtra, Rajasthan, and Tamil Nadu are actively promoting MAR to replenish depleted aquifers. Such forms of MAR development have been targeted for drought-prone regions of the country with little or no attention given to the wetter, flood-prone regions. As groundwater use has significantly expanded throughout the region in recent decades, signs of overexploitation have emerged even in flood-prone regions of the Ganges basin in Bangladesh, India, and Nepal (Saha et al. 2016).

New approaches to adapt and mitigate against climate change impacts on water supply, agriculture, food security, and livelihoods must be identified and put into practice. There is a pressing need to test and promote evidence-based approaches that are cost effective, socially inclusive, and scalable. There is great scope for innovation leading to integrated solutions that contribute positively toward improved flood, drought, and groundwater management and potentially have far-reaching cobenefits for communities in both rural and urban areas. To be successful, these approaches must be pragmatic, affordable, and developed together with, and owned by, vulnerable farming communities to enhance their adaptive capacity. This case study examines the opportunities and constraints of two such approaches by:

- Introducing and giving a brief conceptual analysis of each approach;
- Detailing the state of knowledge for each, focusing mainly on performance- and impact-related aspects; and
- Outlining the challenges, gaps, and ways forward for wide-scale implementation.

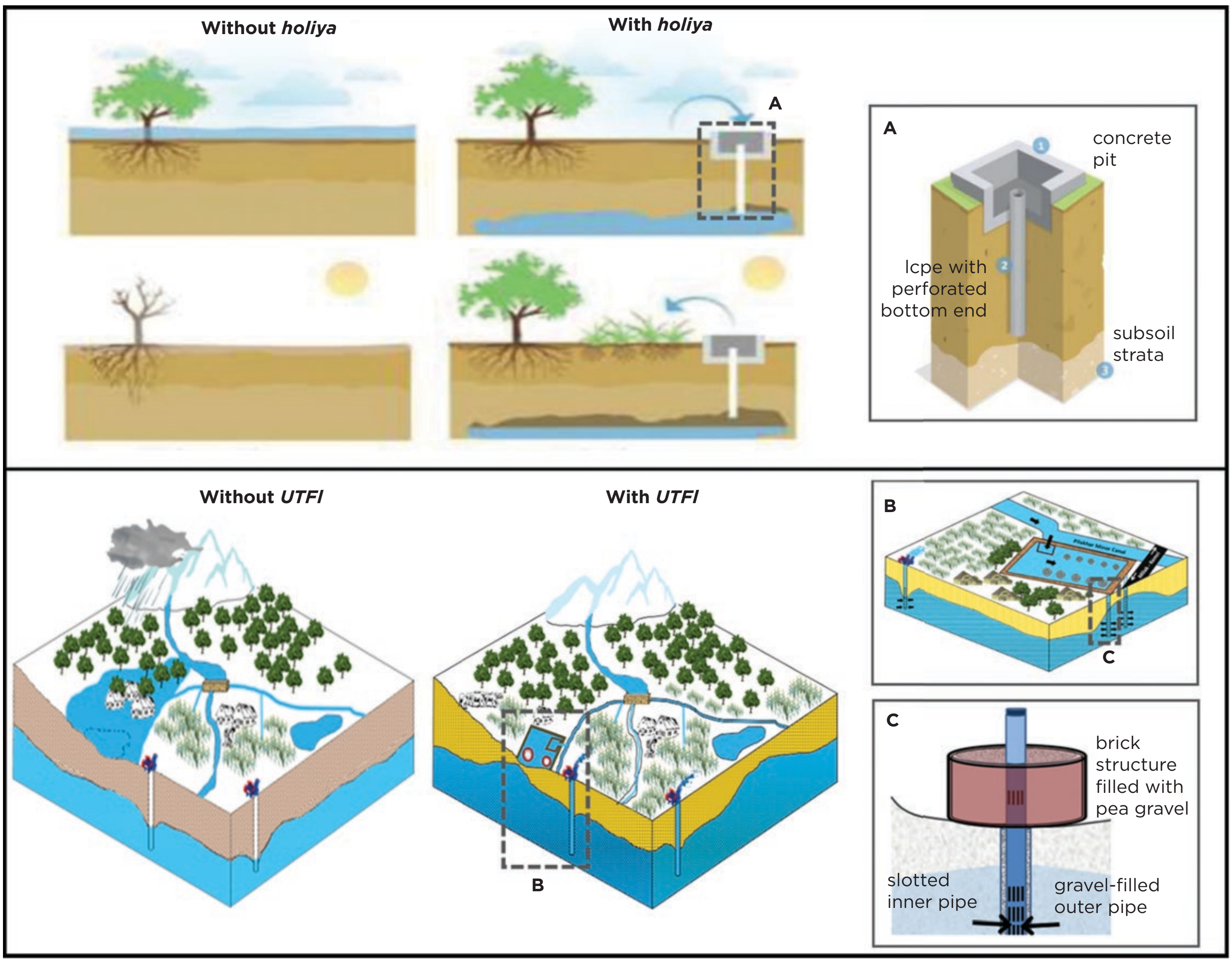
The two approaches presented in this case study were developed independently in different states in India (Gujarat and Uttar Pradesh) and have been brought together here for the first time.

Introducing the Two Approaches

There are two simple yet innovative approaches that address problems associated with a surplus of water at a time or place and a scarcity of water at another time or place. The first, known as the holiya, is a small-scale intervention at the individual farm level to address problems related to extreme seasonal water variability. The second approach, UTFI, is an off-farm intervention to address the same types of water management issues at a community or river basin level. An overview of the characteristics of the two approaches is shown in figure 1 and table 1 and described below.

Although MAR approaches have been applied around the globe over the past six decades (Dillon et al.2018), holiyas and UTFI are novel and have yet to be mainstreamed into development plans, strategies, and MAR guidelines (CGWB 2000). Mainstreaming is unlikely without policy research that demonstrates a solid proof of concept and a viable business case.

FIGURE 1. Schematic Representations of the Functioning and Implementation Design for Holiyas and UTFI



Source: Top Pane: adapted from Bunsen and Rathod (2016). Bottom Pane: adapted from Pavelic et al. (2015).
Note: UTFI = underground transfer of floods for irrigation.

TABLE 1. Overview of the General Characteristics of Two Interventions

Characteristic	Holiya	UTFI
Source of water	Local field runoff	Upstream catchment runoff diverted from rivers or irrigation canals during high flows
Issues addressed	Local flooding/inundation (either event-based or seasonal), waterlogging, groundwater depletion, and groundwater salinization	Seasonal flooding from high flows upstream and groundwater depletion
Aquifer targeted	Upper 8 to 10 meters of alluvial deposits, sometimes extending to depths of 25 meters	Upper (25 to 30 meters) unconfined alluvial aquifer (upper sequence of the Indo-Gangetic Plain aquifers)
Climatic conditions	Semiarid	Humid subtropical
Scale of consideration	Farm level	Community level through river basin level when scaled up
Recharge technology	Collection pit and perforated pipe to drain local fields by gravity	Retrofitted community ponds through pond floor or recharge wells depending on the stratigraphic conditions
Recharge timing	Largely monsoonal (based on rainfall patterns)	Strictly monsoonal based on flow (requires constraining); pond is dormant during the dry season
Recovery technology	Pipe fitted with electric or diesel pump to recover water locally	No specific infrastructure; utilizes existing pumps in nearby wells
O&M activities	Groundwater pumping, pit desilting, pipe unclogging, and pump repair	Activating and deactivating recharge; desilting pit, pond, filters, and recharge wells
Investment model	Either farmer-funded or shared costs between farmer and NGO investor	Investor-driven with in-kind community support
Institutional arrangements	Individual farmer	Community-managed through water use committee linked to high-level institutions
Initiation	Mid-1990s, ramping up in mid-2000s with the involvement of several NGOs	Conceived in mid 2010s in Thailand and piloted in the Gangetic Plain of India since 2015

Sources: Bunsen and Rathod 2016; Garg 2016; Pavelic, Brindha, et al. 2015; Reddy, Pavelic, and Hanjra 2017.
Note: NGO = nongovernmental organization; O&M = operation and maintenance; UTFI = underground transfer of floods for irrigation.

Holiyas

Holiyas, also referred to as *bhungroo*, emerged in North Gujarat in the mid-1990s at the grassroots level through spontaneous farmer-to-farmer transmission (Bunsen and Rathod 2016; Garg 2016). NGO-driven efforts since the mid-2000s have boosted implementation to more than 100 systems constructed by NGOs and nearly 200 by farmers. It is likely that water scarcity is one reason behind their emergence because the Patan and Banaskantha districts where holiyas can be found are among the most groundwater-depleted in Gujarat (Shah 2014). The shallow aquifers in the Patan district are alluvial deposits composed of coarse sand, gravel, pebbles, and fine and clayey sand of moderate to high productivity (CGWB 2014). Naturally occurring saline deposits and hydrogeological complexity in the area leads to high variability where saline groundwater is encountered.

A holiya system is typically composed of little more than a perforated pipe with the top end housed in a square-shaped concrete collection pit with side lengths of 1 meter or less (figure 1). The pipe diameter is about 100 millimeters (4 inches), and the depth of penetration is usually 8 to 10 meters, though some may be as deep as 25 meters. Ideally, the holiya is positioned within the lowest point in a farm field where it can be most effective in draining monsoonal rains that accumulate from the topsoil's low-infiltration capacity. The holiya acts to reduce or avoid water inundation that damages field crops. Perforations in the lower part of the pipe enable surface water to recharge shallow groundwater by gravity alone and be held within the pore spaces of the alluvial layers. The rate of movement (drift) of infiltrated water within the aquifer is believed to be low, so the recharged water adds to local groundwater storage and can be recovered during the winter or summer months to irrigate crops or for livestock. Little technical knowledge is required for holiya construction. The total depth and slotted intervals of the pipe as well as the method of pipe completion at the surface are among the few critical elements of good design. Costs related to operation and maintenance (O&M) are incurred in pumping out water, desilting the pit, unclogging the pipe, and repairing and replacing the pump.

UTFI

UTFI recharges depleted aquifers with wet-season high flows, adding to local groundwater storage and mitigating flooding in downstream areas (figure 1). The stored recharge water may later be recovered via existing local wells for domestic supplies and irrigation.

UTFI can enhance the ecosystem with flood control, groundwater recharge, and dry-season water availability. The socioeconomic and environmental benefits of UTFI are most apparent in large-scale projects that involve upstream-downstream linkages. Clustering individual UTFI interventions within a local community enables scaling up to the small watershed or catchment scale (from tens to thousands of square kilometers).

The idea behind UTFI emerged in the early 2010s from MAR trials and desktop analysis in the Chao Phraya basin, Thailand (Pavelic et al. 2012). UTFI implementation has so far focused on the Ganges River basin and has had some similarities to the Ganges water machine concept, which was developed in the 1970s and revisited in the 2010s (Amarasinghe, Mutuwatte, et al. 2015; Revelle and Lakshminarayana 1975).

Evaluation Approaches

Knowledge of holiyas is based exclusively on two rapid assessment studies carried out in North Gujarat by students under the International Water Management Institute (IWMI)-TATA program in 2015–16 (table 2). The studies were similar in seeking to empirically deduce the holiya functioning as well as socioeconomic and environmental impacts. Bunsen and Rathod (2016) surveyed 41 farmers across multiple villages with detailed work in one village (Ekalva). Focusing solely on this village, Garg (2016) conducted almost 50 interviews with farmers, including owners and non-owners of holiyas, laborers involved with holiya construction, and NGO representatives.

The evidence base for UTFI is drawn from research for development project that began in 2015. Studies have focused on pilot testing and evaluation using multidisciplinary approaches at the village scale supplemented by modeling studies at the basin scale (table 2). The scope of activities includes site suitability assessments, pilot testing and demonstration, hydroeconomic modeling, institutions and policy analysis, community mobilization, and capacity building. For this assessment, the findings from those activities are separated into two sets. One relates to village-level pilot testing and evaluation, and the other includes analyses at the basin scale to assess opportunities for scaling up. Various project documents have been utilized for this analysis (Brindha and Pavelic 2016; Chinnasamy et al. 2017; CSSRI 2017; Gangopadhyay, Sharma, and Pavelic 2017; Pavelic, Brindha, et al. 2015; Reddy, Pavelic, and Hanjra 2017).

Technical Performance and Beneficial Impacts

Holiyas

Holiyas were evaluated for their technical performance, as well as for their beneficial impacts from an economic, environmental and social perspective.

TABLE 2. Site Details and Evaluation Methods

	Holiya	UTFI (P)	UTFI (B)
Site(s) evaluated	Banaskantha and Patan districts, Gujarat, India	Jiwai Jadid village, Rampur district, Uttar Pradesh, India	Ramganga basin, India
Evaluation methods applied	Interviews and surveys of holiya owners and non-owners, laborers, and NGO representatives in multiple villages	Field testing of one pilot trial site and group discussions	Hydrologic, hydraulic, and economic modeling

Note: B = basin-scale intervention; NGO = nongovernmental organization; P = pilot-scale intervention; UTFI = underground transfer of floods for irrigation.

Technical Performance

The majority of the holiyas examined functioned effectively. Some did not work well because of poor setting of the pipe depth, inappropriate siting, overextraction leading to high groundwater salinity, low-quality construction materials, pipe clogging from high suspended sediment content, and inadequate attention to structure maintenance.

The hydrogeological conditions at a selected location are critical to the performance and long-term functioning of holiyas. For example, holiyas that intercept highly saline deposits face constraints in recovering adequate quantities of fresh water because even low levels of mixing between recharged and native water is a major issue. The specific ways in which hydrogeologic variables influence the capacity to infiltrate and recover water remain unclear.

Economic and Environmental Aspects

Most holiya owners claim to benefit from extended water access during the growing season and improved drought resilience. In some cases, greater water availability enabled crop diversification. Estimates given by interviewees suggest that agricultural production rose by about 20 to 25 percent, boosting income and improving farmers' drought resilience. Although the capital cost of the structures is reasonable, particularly when farmers organize construction with local contractors, some farmers claim that the cost is a major disincentive. In the Ekalva village, the recent introduction of canal water at a cheaper cost than holiya water could have disincentivized farmers' use of holiyas. However, holiyas remained relevant because canal water is not available year-round or throughout the village.

Social Aspects

Most farmers interviewed believe the introduction of holiyas to be a success, but this belief is understood only in general terms. No specific type of holiya (either self-constructed or NGO-constructed) was thought to be better than another. Holiya water used for domestic purposes is also perceived to provide health benefits (such as reduced joint pain, stomach pain, and indigestion), presumably when compared to higher-salinity tubewell water.

Most owners claim to benefit from flood mitigation improvements as well as reduced soil erosion. Other positive externalities emerge where holiya owners drain away problematic flows from neighboring fields. However, during extreme rainfall events, there are limits on the effectiveness of holiyas in averting inundation. Well-off tubewell owners used to sell water to poorer farmers, but this practice has declined since holiyas have been built, easing pressure on groundwater resources and averting the need to deepen tubewells every few years.

Farmers in the area have a good understanding of the groundwater system and the role of holiyas in augmenting groundwater resources. Owners of holiyas gain direct benefits from their endeavors and thus tend to learn from their experience and that of other farmers on ways to improvise and improve the design. Simplicity is critical to successful farmer adoption. For example, establishing a pair of holiyas near each other means growers can use a single pump and save on capital costs. Farmers rejected NGO attempts to improve the design by adding a gravel layer to the collection pit to filter water prior to recharge because it added cost and effort with limited perceived benefit. One NGO reportedly assigns ownership to women farmers, but it is not clear whether this achieves the goals of women's empowerment and stronger social outcomes (for example, by greater investments in farm improvements and education).

UTFI

Implementation of UTFI in the field has focused on pilot demonstration and testing on the Gangetic Plain in western Uttar Pradesh in India. The pilot trial site at the Jiwai Jadid village was selected after regional mapping, desktop studies, and field surveys to examine the biophysical conditions and local communities' need for UTFI as outlined in Pavelic, Brindha, et al. (2015).

The Jiwai Jadid village in the Rampur district relies almost entirely on agriculture. About 90 percent of the area is under cultivation supported by good alluvial soils and full irrigation coverage from tubewells and canals. A diverse mix of castes resides in the village, and government data show 17 percent of households have below-poverty-line ration cards. Paddy and wheat are the major crops grown. Small and marginal farmers account for 77 percent of the village. More than 90 percent of households in the village own private tubewells for domestic and irrigation supplies. Although small and moderate floods occurred in the decade prior to implementing the trial, overabstraction of groundwater is the village's most critical water resource issue. Further detail of the biophysical and socioeconomic context for the village and wider area are available in the baseline studies (IWMI 2017; LNRMI 2017; TERI 2017).

The UTFI pilot rehabilitated a single abandoned village pond with 10 recharge wells (figure 1) sunk into the base to depths of 25 to 30 meters. The wells encountered fine to medium sand layers, with occasional clay lenses, that form the upper unconfined aquifer, which is the source of much of the groundwater pumping in the area. Water is siphoned into the pond from an adjacent canal that receives river flows in the monsoon period. Water, filtered through the wells, recharges the aquifer. In the dry season, the stored flood water is recovered via existing domestic and irrigation wells. An upper blanket of 6 to 7 meters of heavy clay soil meant that well-recharge methods had to be applied. It also accounts for the negligible levels of seepage observed beneath the base of the canal. High population density and intensive year-round cultivation make land availability a constraint. However, ponds owned by the community are often abandoned because farmers have switched from ponds and canals to private groundwater wells as the dominant source of irrigation water.

Technical Aspects

The UTFI system operates in recharge mode during the monsoon months when water in the adjacent Pilankar minor canal is high, signifying an excess of surface water flows as the canal diverts water from the nearby Pilankar River. In the first full season of operation in 2016, total recharge was 40,000 cubic meters over 85 days of operation. A wetter year in 2017 resulted in 60,000 cubic meters of water recharged. With modest refinements in operational management, the attainable volume would be about 70,000 cubic meters per year. Recharge water is silt-laden, with total suspended sediment values in the pond water measured at 300 to 400 milligrams per liter. Intraseasonal declines in recharge rates are observed as a result of siltation from turbid water. Desilting of the pond floor and gravel filter is performed annually, and the recharge wells have been desilted on one occasion using an airlift pump.

A series of piezometers around the structure measure groundwater-level changes in the vicinity of the pond. Water-level buildup attributable to UTFI appears to be small because of the physical properties of the aquifer (high aquifer diffusivity) and further masked by the more dominant influence of natural recharge.

Detailed water quality monitoring indicates that nutrients, arsenic, and pesticide levels in the recharge water and the receiving groundwater have been detected, but their levels are not a concern relative to the Indian drinking water standard (BIS 2012). However, following recharge, fecal coliforms and some heavy metals, such as arsenic and mercury, are detected at higher levels than both the Indian standard and the World Health Organization drinking water standard in recharged groundwater and all monitored groundwater, including far from the pilot site where impacts from recharge operations are not expected. This strongly suggests that microbial and some heavy metal contamination existed in the Jiwai Jadid village pond prior to the pilot and is unrelated to the intervention, though geochemical reactions stimulated by the recharge activities may have contributed to the mobilization of these contaminants. The microbial pollution of groundwater is not surprising because the village has poor wastewater management and microbial contaminant inputs that appear to exceed the natural capacity of the aquifer for attenuation.

Environmental Impacts

Integrated hydrological modeling has been used at the Ramganga basin scale (19,000 square kilometers) to examine the biophysical implications of scaling up and to explore alternative options (Chinnasamy et al. 2017). The model considered a distributed arrangement of UTFI interventions across the basin, capturing between 10 and 50 percent of the cumulative outflow that would otherwise discharge out of the basin under baseline conditions. The results show that, with 50 percent capture, groundwater level declines could be slowed and then reversed with a 7-meter rise in levels across the basin within the 11-year simulation period considered (1999–2010). The increase in groundwater levels over that same period brings cobenefits in terms of an increase in base flow contribution to the Ramganga River. The reduction in net basin outflow would reduce peak discharge, lowering the magnitude (that is, the return period and inundated area) of current floods. For example, a 20 percent reduction in peak flows at the outlet of the basin converted a 15-year flood peak to eight years, a five-year peak to three years, and a two-year peak to just more than one year. The modeling affirms that, in theory, with appropriate basinwide UTFI implementation, flood impacts can be mitigated and both groundwater storage and river base flow enhanced.

Based on the trial results (CSSRI 2017), an estimated 17,000 village ponds would need to be converted to reduce outflow by 20 percent of the mean annual July to September flow of about 6,000 million cubic meters (based on the design recharge volume indicated below). In Rampur district alone, where mapping has taken place, there are 1,800 ponds, indicating a high potential for scaling up within the basin. The high degree of extrapolation from the one trial pond to basin scale suggests a high degree of uncertainty in the scaling-up parameters, so these parameters provide only a tentative indication of the scaling potential.

Economic Performance

Estimates of the UTFI-attributed agricultural output are based on a design recharge volume of 70,000 cubic meters, of which 75 percent is used for agriculture and the remaining 25 percent added to environmental flows. The quantity is enough to irrigate either 8 hectares of summer rice or 11 hectares of maize (table 3). Net economic returns range from US$66 per hectare for dry season rice to US$158 per hectare for maize. IWMI is presently undertaking a more comprehensive assessment of the socioeconomic and environmental impacts at the household and village scales.

Institutional Aspects

Community participation in the pilot has been formally registered under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), a long-standing national flagship program focused on natural resource management and livelihood improvement administered by India's Ministry of Rural Development. This provides a formal mechanism for ongoing resourcing to support annual maintenance of the infrastructure. In the two years of implementation to date, MGNREGA provided the mechanism to involve the community to desilt the basin but was unable to handle the redevelopment of the wells, which required capital costs for specialist equipment (an air compressor). Future efforts will seek to further mobilize the community and instead use cheaper, locally available pumps for maintenance.

TABLE 3. Quantitative Technoeconomic Performance

	Holiya	UTFI (P)
Installation costs (US$ per structure)	40–540[a]	2,700[b]
Maintenance costs (US$ per structure per year)	Unknown	550[b]
Net economic return (US$ per structure per year)	Unknown	721–1241[b]
Volumes of water stored (x 10^3 m^3 per structure per year)	Unknown	70[c]
Potential area irrigated during dry season (hectare)	Unknown	8–11[c]
Water quality changes	Reduced salinity	No net impact

Sources: a. Alam and Pavelic, forthcoming; b. Bunsen and Rathod 2016; c. pilot trial results.
Note: m^3 = cubic meter; P = pilot-scale intervention; UTFI = underground transfer of floods for irrigation.

Although the economic incentive offered by MGNREGA is sufficient to mobilize the community to address the hardware components of UTFI, it is not sufficient to address other components that are needed to ensure effective and sustainable functioning over the long term. One of the key challenges is that the village is institutionally weak. There are no self-help, water user, or farm groups or NGOs. The local government (or *Panchayati Raj*) is the only functioning institution in this village and many surrounding villages.

The institutional arrangements for UTFI are under development. Responsibility for the management of the UTFI intervention at the Jiwai Jadid village is being handed over to the district authorities, with links to the Panchayati Raj and the local community. The project team is working to increase the capacity of district officials and the local community to operate and manage the system effectively over the longer term.

Community Perceptions

The local community perceives the benefits of UTFI to be increased availability of water, especially during the monsoon and winter months. Farmers said they spent less time irrigating fields, and householders spent less time and effort collecting water from hand pumps. The community also values the cleanliness in the pilot area, which previously was used for village waste disposal. However, some farmers say the system adds little value because natural recharge already takes place in the wet season, whereas water shortfalls are greatest during summer months. In their view, using canal water for recharge in summer would be most beneficial. This view is contentious because it would create direct competition and risk avoidable conflict with surface water irrigators. Some farmers also perceive floods as having a beneficial effect on soil fertility, reaffirming the view that trading off UTFI with other potential benefits must be given appropriate attention and analysis before larger-scale implementation.

Gender Dimensions

UTFI is in theory a gender-neutral approach that benefits men and women equally. However, examination of gender across socioeconomic groups in the village reveals a complex situation. In this village, and throughout the region, women are less visible than men within the public sphere because of deeply entrenched social and cultural barriers. Women do not participate in Panchayat meetings, nor are they engaged in managing community assets. Their social capital and networks are highly constrained compared to men.

The direct role for women in UTFI is also limited and reflects their degree of inclusion in village agriculture.

Where caste-related rules allow, women largely act as laborers. Women believe that UTFI is a domain for men, so few would be willing to maintain the infrastructure, even if financial incentives were offered. Women from upper caste communities are unwilling to undertake O&M or be part of the water committee. Men, on the other hand, are largely willing to undertake O&M and contribute to minor maintenance, but they are not ready to organize themselves to take complete responsibility or ownership for UTFI. They prefer that the Panchayat own the project and MGNREGA be responsible for maintenance. The village's modest economic status means it has little ability to directly contribute to infrastructure, and external financial and technical support is needed.

Comparative Analysis

Table 4 summarizes the comparative impacts of sustainability indicators, and an analysis of strengths, weaknesses, opportunities, and threats (SWOT) in table 5 highlights the advantages and disadvantages associated with the two approaches. Holiyas may be the intervention of choice where local benefits are sought and where a low level of residual risk is preferred. UTFI, on the other hand, addresses larger issues and may achieve more widespread benefits at a commensurately higher level of risk. This risk is largely a reflection of the challenges associated with participatory management of common pool resources. Local farmers know they receive only indirect benefits from UTFI because enhanced recharge for these projects is intended to increase groundwater availability for several farmers in the immediate area. This presents a challenge for effective community participation and highlights the reliance of the community on higher-level institutional linkages to provide capacity, knowledge, and financial resources.

The SWOT analysis illustrates that the spatiotemporal and climatic domains of suitability of the two approaches are different (figure 2). Holiyas can capture only small volumes of water and may be better suited to drier climates than UTFI. Holiyas may harvest both storm-related or seasonal floods, whereas UTFI is better suited to larger-scale and longer-lasting floods than those that are rapid or localized.

Scaling-up Status and Theoretical Potential

The two techniques, themselves being at different scales, have slightly different potential profiles for scaling-up.

Holiyas

There is little documented evidence to suggest that holiyas have been successfully implemented in areas beyond North Gujarat. It is unclear why MAR has boomed in the Saurashtra and Kutch districts to the south and east but not in the Banaskantha and Patna districts, all of which are equally groundwater stressed. NGO-led promotion of the holiya has reportedly led to uptake in the Indian states of Andhra Pradesh, Jharkhand, Madhya Pradesh, and Odisha (Naireeta Services 2018). Similar efforts are believed to be underway in Bangladesh, Madagascar, and Togo, though publications on this topic are not available. Some documentation from a research project in Ghana's northern region is available (Owusu et al. 2017), but field findings have yet to emerge.

UTFI

There have been modest successes in plans for scaling up UTFI, concentrated in areas closest to the pilot site. UTFI has been adopted as a key intervention within the district irrigation plan (DIP) for Rampur, prepared under the national flagship program, Pradhan Mantri Krishi Sinchayee Yojana (Prime Minister's Irrigation Program [PMKSY]). Fifty sites are proposed under the DIP with a capital investment of US$1.2 million (₹7.5) over five to seven years. The geographic focus is on the subdistricts categorized as having critically overexploited groundwater. A similar process is anticipated to emerge in the Etah district, 150 kilometers south of Rampur. Opportunities to scale up have been facilitated through close engagement and support provided by district officials and by having a project team member sit on the committee of the district nodal agency of PMKSY.

Over the longer term, successful scaling up of UTFI depends on its convergence with government policies and development programs taken forward by state and local governments, NGOs, and the private sector. Some potential entry points to include UTFI in Indian policies and programs include the following:

- Sustainable groundwater management is a thematic priority area of the government linked to various national programs including the National Aquifer Mapping and Management Programme, Master Plan for Artificial Recharge to Ground Water, and others.
- Integrated Watershed Management Program is implemented under the flagship program, PMSKY (Watershed Development Component).
- Corporate social responsibility contributions from the private sector are required under a 2014 law mandating that 2 percent of average net profits be invested in critical social needs such as education, gender equality, and hunger.

TABLE 4. Comparative Impacts of Sustainability Indicators

Factors and associated indicators	Holiya	UTFI (P)	UTFI (B)
Technical performance			
Flood water recharge achieved	Largely yes, but specific details unknown	Yes	Yes
Soil erosion reduced	Largely yes	n.a.	Unknown
Groundwater quality improved or at least maintained	Unknown	Yes	Unknown
Recharge structure maintained	Unknown	Yes (with external support thus far)	Unknown
Economic performance			
Agricultural production increased	Largely yes, by about 20 to 25 percent	Yes (inferred thus far)	Yes
Food security or farm incomes enhanced	Largely yes, but specific details unknown	Yes (inferred thus far)	Yes
Form of benefits for farmers	Direct	Indirect	Indirect
Opportunity costs	Likely small for farmers because capital and O&M costs are minimal; water ponds in fields would not otherwise be used productively	Small apart from limited farmers who see flooding as beneficial for crop production	
Environmental impacts			
Dry-season groundwater storage enhanced	Largely yes	Limited because of high aquifer diffusivity	Declining groundwater level trends can be reversed
Domestic or livestock water supplies enhanced	Largely yes	Yes	Yes
Pumping costs (energy consumption) reduced	Unknown	Likely to be negligible	Yes
Baseflow to surface water bodies enhanced	Unknown	Difficult to establish; likely to be negligible	Yes
Flood risk reduced	Largely yes, except for extreme events	Difficult to establish; likely to be negligible	Yes
Community perceptions			
Concept and rationale understood	Sufficiently well	Partially	Unknown
Intervention operated correctly and potential conflicts avoided	Unknown	Yes, with external support	Unknown
Mechanism for O&M cost outlay developed	Unknown	Under development	Unknown
Infrastructure maintained	Unknown	Yes, with external support	Unknown

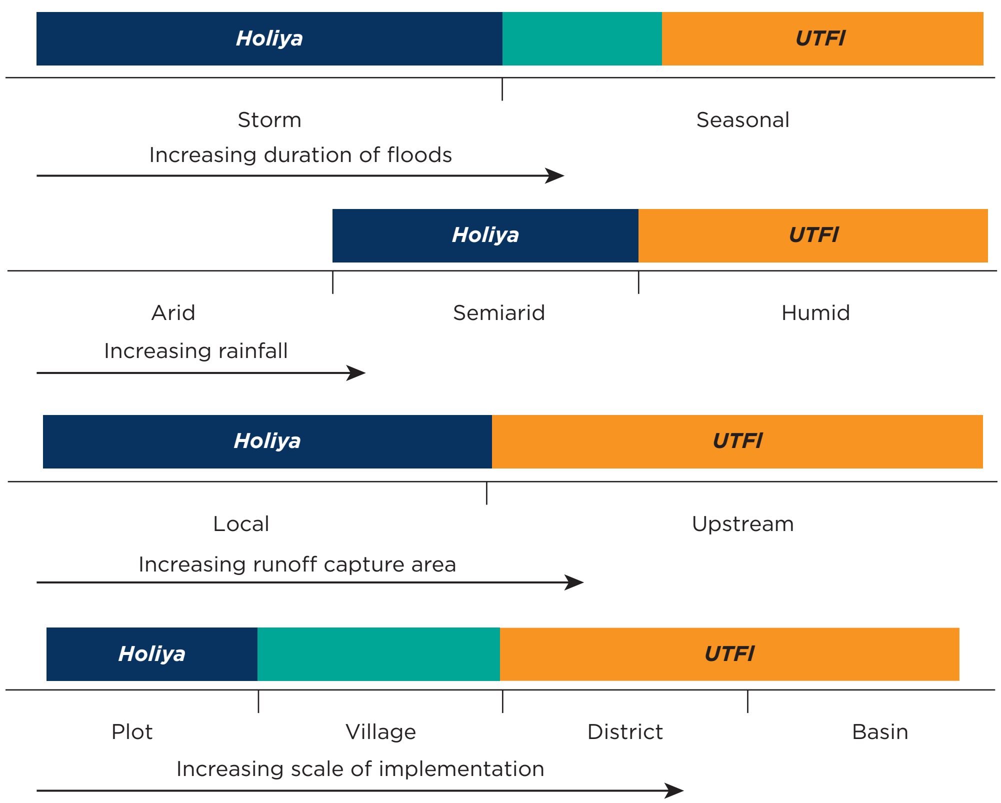
Sources: Bunsen and Rathod 2016; Garg 2016; Pavelic, Brindha, et al. 2015.
Note: B = basin-scale interventions; n.a. = not applicable; O&M = operation and maintenance; P = pilot-scale interventions; UTFI = underground transfer of floods for irrigation.

TABLE 5. SWOT Analysis for the Two Intervention Types

	Holiya	UTFI
Strengths	Simplicity; low cost; direct benefits for participating farmers; and greater farmer empowerment, which potentially includes women	Simplicity, good cost benefits, and positive impacts if scaled; strong evidence base to underpin engagement at policy levels
Weaknesses	Localized nature, dependence on year-to-year climate in saline environments as minimal buffering created below ground, and lack of verifiable evidence on performance and functioning; limited evidence base	Dampened groundwater response because of aquifer characteristics, opportunity costs (mitigating beneficial floods), and benefits are indirect for the participating farmers; more complex institutional management
Opportunities	Vast potential likely throughout much of the South Asia region (see "Scaling-up Status and Theoretical Potential")	Vast potential throughout much of the region (see "Scaling-up Status and Theoretical Potential"); some uptake by government to date
Threats	Sustainability and contamination by fertilizer and pesticide residues	Risk of poor local governance, conflicts with downstream water users, and potential for contamination

Note: SWOT = strengths, weaknesses, opportunities, and threats; UTFI = underground transfer of floods for irrigation.

FIGURE 2. Spatio-Temporal and Climatic Domains of Suitability for Holiyas and for UTFI



Note: UTFI = underground transfer of floods for irrigation (UTFI).

Regional Suitability Analysis

The relatively brief duration since the two interventions were initiated, particularly in the case of UTFI, has contributed to the limited level of take-up. At such an early stage, it is worthwhile to explore the geographic areas where there is potential scope for implementation within India and the wider region. Both forms of intervention have prerequisite conditions that must be met before proceeding with implementation. Many of these conditions are common to both (table 6).

The potential for UTFI has been assessed throughout South Asia as part of a global-scale assessment, which is likely applicable to holiyas as well by default. Alam and Pavelic (forthcoming) provide specific details of that assessment. In brief terms, a spatial analysis was undertaken at a 0.5-degree grid-scale resolution with results aggregated to the country level. The analysis relied on publicly available data sets of the key indicator parameters for three areas related to floods, droughts, and aquifer characteristics. Ranks and weights were applied to each parameter followed by overlay analysis.

The results suggest widespread prospects for UTFI throughout South Asia. A total area of 169 million hectares of crop land is assessed to have moderate to high potential for UTFI across the seven countries considered (table 7). These potentially suitable areas are home to about 80 percent of the region's population (1.4 billion people). The country with the highest potential in terms of land area is India, followed by Pakistan and then Bangladesh.

For potential investors and proponents, maps and data of this kind help form the basis for screening and first-level decision making about the feasibility of these interventions and help prioritize steps needed to move forward. A high degree of heterogeneity and local contextual considerations means that within any given region, more-detailed assessments would be needed to narrow the best-suited areas and develop plans for implementation (Pavelic, Brindha, et al. 2015).

Knowledge Gaps and Outlook

Holiya

More detailed exploration of holiyas is warranted based on the rapid assessments' generally positive findings, revealing more than 300 sites established in two districts in North Gujarat. Gaps in knowledge and capacity remain as follows:

- Recharge capacity of holiya structures under different hydrogeological conditions
- Potential water quality–related health risks for farm households using holiya water for domestic purposes (such as microbial quality or mobilization of arsenic)
- Long-term performance and viability of maintaining holiya structures
- Economic viability and life cycle costs across different settings
- Gender- and equity-related benefits
- Local capacity to undertake scientifically based implementation

Knowledge in these areas, combined with reconnaissance studies over wider areas, would shed light on the constraints to wider uptake of holiyas in Gujarat and potentially other regions.

An interesting parallel to the holiya approach has emerged in the more humid conditions of eastern India, which floods

TABLE 6. Checklist of Minimum Prerequisites and Enabling Conditions for Successful Implementation

Factor	Holiya	UTFI
Regular flooding with negative socioeconomic impacts such as crop or property damage and livestock or human casualties	✓	✓
Short- or long-term droughts leading to domestic or irrigation shortfalls in water supply	✓	✓
Suitable aquifers in terms of permeability, low salinity, and sufficiently deep groundwater levels	✓	✓
Absence of nearby major pollution sources that may contaminate the floodwater or groundwater	✓	✓
Land for conversion to recharge structures that is close to a flood water source (river, canal, and so on)	n.a.	✓
Interest and participation of local farmers and institutions to facilitate effective and sustainable use of the interventions	✓	✓

Note: n.a. = not available; UTFI = underground transfer of floods for irrigation.
The conditions reflected in the top three rows are included in the UTFI mapping assessment.

TABLE 7. South Asia Populations and Land Area with Moderate to High UTFI Prospects

Country	Area (million hectares)	Population (millions)
Afghanistan	1.6	12.9
Bangladesh	8.6	138.6
Bhutan	0.1	0.6
India	137.2	1,088.8
Nepal	2.5	32.3
Pakistan	18.0	157.8
Sri Lanka	1.4	11.4
Total	169.4	1,442.4

Source: Adapted from Alam and Pavelic, forthcoming.
Note: UTFI = underground transfer of floods for irrigation.

regularly, and where groundwater dependence is low and water tables are shallow. The shallow water tables preclude consideration of holiyas and UTFI. Instead, the vertical drain has been tested experimentally in the Vaishali district in Bihar (Prathapar et al. 2018). Results show that the drain bypassed a 6-meter layer of clay and better connected the floodwater to the aquifer, draining 26 cubic meters per day on average when groundwater levels started to recede. The vertical drain shortened the duration of seasonal waterlogging in time for the winter wheat crop. It would be useful to examine the scaling-up potential for this approach as well.

UTFI

The state of knowledge and experience on UTFI in the Ganges basin is at an intermediate level, though under a limited set of biophysical and social conditions. As the research progresses, the evidence base for UTFI will be further strengthened. Future research, building upon the existing work described in this case study, should focus on the following gaps and challenges:

- Enhancing village participation and ownership through local institutions to ensure effective functioning and performance over the long term
- Establishing how climate change will affect water availability and demand and how this would affect the performance of UTFI and parameters for scaling up
- Developing practical, comprehensive guidelines, and operating procedures for successful rollout of UTFI programs on the Gangetic Plain
- Creating a larger number of demonstration sites to test other hydrogeological, agroecological, and socioeconomic conditions in India and potentially other countries in South Asia

Key Messages Going Forward

The findings presented here suggest that holiyas and UTFI offer affordable, practical, and effective ways for individual and groups of farmers to respond to floods, droughts, and groundwater overexploitation. The two techniques offer a range of scales (farm to basin) and contribute to a compelling narrative regarding the transformation of a water hazard (floodwater) into a resource (groundwater). They present an opportunity for South Asian farmers to boost agricultural productivity and diversity, thereby improving livelihoods and drought resilience. Further, the two approaches offer highly desirable, nature-based solutions that are environmentally benign and do not require large infrastructure or transportation of water across great distances.

In principle, there is a clear scope to implement these interventions more widely across much of South Asia, but the geographic scope of both approaches has so far been limited to India. To scale up the approaches, South Asian countries need to improve enabling conditions through policy dialogues, build awareness among stakeholders, and support operational, technical, and institutional capacity building to effectively manage holiyas and UTFI. Policy makers and investors can consider the two approaches when making investment decisions related to sustainable development goals, water-related disasters, climate change adaptation, watershed management, and rural livelihood development.

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NOTE

1. International Water Management Institute (IWMI), Vientiane, Lao People's Democratic Republic.

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