

Utilizing Floodwaters for Recharging Depleted Aquifers and Sustaining Irrigation

Lessons from Multi-scale Assessments in the Ganges River Basin, India

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Groundwater issues addressed

- Groundwater over-abstraction
- Groundwater quality/human health
- Salinity issues/intrusion
- Land subsidence
- Ecosystem degradation
- Food security/livelihoods

Type of interventions

- Legal initiative/regulation
- Policy
- Technology application
- Local initiative



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Front cover photograph shows the pilot site established to test the Underground Transfer of Floods for irrigation (UTFI) approach in Jiwai Jadid village, Rampur District, Uttar Pradesh, India (*photo*: Prashanth Vishwanathan/IWMI).

About the Groundwater Solutions Initiative for Policy and Practice (GRIPP) Case Profile Series

The GRIPP Case Profile Series provides concise documentation and insight on groundwater solution initiatives from around the world to practitioners, decision makers and the general public. Each case profile report covers a contemporary intervention (innovation, technology or policy) or a series of applied groundwater management-related approaches aimed at enhancing groundwater sustainability from an environmental and socioeconomic perspective at local, national or international level. Integrated analysis of the approach, background, drivers, stakeholders, implementation, experiences and outcomes are discussed with a view to illustrating best practices, factors that could lead to success or failure, and wider applicability.

Abstract

English

Pragmatic, cost-effective, socially inclusive and scalable solutions that reduce risks from recurrent cycles of floods and droughts would greatly benefit emerging economies. One promising approach known as *Underground Transfer of Floods for Irrigation* (UTFI) involves recharging depleted aquifers with seasonal high flows to provide additional groundwater for irrigated agriculture during dry periods, while also mitigating floods. It has been identified that there is potential for implementing the UTFI approach across large parts of South Asia. The first pilot-scale implementation of UTFI was carried out in a rural community of the Indo-Gangetic Plain in India, and performance of the approach was assessed over three years from a technical, environmental, socioeconomic and institutional perspective. The results are promising and show that UTFI has the potential to enhance groundwater storage and control flooding, if replicated across larger scales. The challenges and opportunities for more wide-scale implementation of UTFI are identified and discussed in this report. In areas with high potential for implementation, policy makers should consider UTFI as an option when making decisions associated with relevant water-related development challenges.

French

Des solutions pragmatiques, rentables, socialement inclusives et évolutives, qui réduisent les risques liés aux cycles récurrents d'inondations et de sécheresses, profiteraient grandement aux économies émergentes. Une approche prometteuse, connue sous le nom de transfert souterrain des crues pour l'irrigation (*Underground Transfer of Floods for Irrigation - UTFI*), consiste à recharger les aquifères épuisés avec des débits saisonniers élevés afin de fournir des eaux souterraines supplémentaires pour l'agriculture irriguée pendant les périodes de sécheresse, tout en atténuant les inondations. Il a été identifié qu'il existe un potentiel pour la mise en œuvre de l'approche UTFI dans de grandes parties de l'Asie du Sud. La première mise en œuvre à l'échelle pilote de l'UTFI a été réalisée dans une communauté rurale de la plaine indo-gangétique en Inde, et les performances de l'approche ont été évaluées sur trois ans d'un point de vue technique, environnemental, socio-économique et institutionnel. Les résultats sont prometteurs et montrent que l'UTFI a le potentiel d'améliorer le stockage des eaux souterraines et de contrôler les inondations, si elle est reproduite à plus grande échelle. Les défis et les opportunités d'une mise en œuvre à plus grande échelle de l'UTFI sont identifiés et discutés dans ce rapport. Dans les zones à fort potentiel de mise en œuvre, les décideurs politiques doivent considérer l'UTFI comme une option lorsqu'ils prennent des décisions liées aux défis de développement liés à l'eau.

Spanish

Las economías emergentes se beneficiarían enormemente de soluciones para reducir los riesgos asociados a los ciclos recurrentes de inundaciones y sequías, que sean pragmáticas, rentables, socialmente inclusivas y escalables. Un enfoque prometedor, conocido como *Desviación subterránea de las inundaciones para el riego* (*Underground Transfer of Floods for Irrigation - UTFI*), consiste en recargar los acuíferos agotados con flujos estacionales de agua y disponer así de aguas subterráneas adicionales para la agricultura de regadío durante los períodos de sequía, al tiempo que se mitigan las inundaciones. Se ha determinado que existe la posibilidad de aplicar el enfoque de UTFI en diferentes partes del Asia meridional. La primera aplicación a escala experimental de la FFU se llevó a cabo en una comunidad rural de la llanura indogangética de la India, y los resultados del enfoque se evaluaron a lo largo de tres años desde una perspectiva técnica, ambiental, socioeconómica e institucional. Los resultados son prometedores y muestran que la UTFI tiene el potencial de mejorar el almacenamiento de las aguas subterráneas y controlar las inundaciones, si se reproduce a mayor escala. En el presente informe se identifican y examinan los retos y oportunidades para una aplicación a mayor escala de la UTFI. En las zonas con un alto potencial de aplicación, los encargados de formular políticas deberían considerar la UTFI como una opción al adoptar decisiones relacionadas con los problemas de desarrollo pertinentes relacionados con el agua.

Hindi

व्यावहारिक, लागत प्रभावी, सामाजिक रूप से समावेशी और स्केलेबल समाधान जो बाढ़ और सूखे के आवर्तक चक्र से जोखिम को कम करते हैं, उभरती अर्थव्यवस्थाओं को बहुत लाभान्वित करेंगे। एक आशाजनक उपागम जैसे सचिाई के लिए बाढ़ का भूमिगत स्थानान्तरण (यु टी ऍफ़ आई/UTFI) के नाम से जाना जाता है में घट चुके जलभरों को मौसमी उच्च प्रवाह से शुष्क अवधि के दौरान सचिाई से की जाने वाली कृषि के लिए अतिरिक्त भूजल प्रदान करना है और इससे बाढ़ को भी कम किया जा सकता है। यह पता चला है कि दक्षिण एशिया के बड़े हिस्सों में यु टी ऍफ़ आई/UTFI उपागम को लागू करने की क्षमता है। यु टी ऍफ़ आई/UTFI का पहला पायलट-स्तर पर कार्यान्वयन भारत में इंडो-गंगेतिक प्लेन के एक ग्रामीण समुदाय में किया गया था, और उपागम के प्रदर्शन के तकनीकी, पर्यावरणीय, सामाजिक आर्थिक और संस्थागत परिप्रेक्ष्य का तीन वर्षों तक मूल्यांकन किया गया था। परिणाम आशाजनक हैं और बताते हैं कि यदि बड़े पैमाने पर इसे दोहराया जाता है, तो यु टी ऍफ़ आई/UTFI भूजल भंडारण को बढ़ाने और बाढ़ को नियंत्रित करने की क्षमता रखता है। इस रिपोर्ट में यु टी ऍफ़ आई/UTFI के अधिक व्यापक पैमाने पर कार्यान्वयन के लिए चुनौतियों और अवसरों की पहचान और चर्चा की गई है। कार्यान्वयन के लिए उच्च क्षमता वाले क्षेत्रों में, नीति निर्माताओं को प्रासंगिक जल-संबंधित विकास चुनौतियों से संबंधित निर्णय लेते समय यु टी ऍफ़ आई/UTFI पर एक विकल्प के रूप में विचार करना चाहिए।

1. Background and objectives

Extreme weather events disproportionately affect large populations in the world's emerging economies (Islam and Winkel 2017). Such regions may be characterized by recurrent cycles of intense rainfall that cause distressing floods and periods of low rainfall that cause seasonal droughts. India is a clear case in point where problems associated with water management are a major national concern (Kumar 2018). The average annual economic impact of monsoonal floods in the country over recent decades is estimated to be more than USD 1 billion with 22 million people affected every year (World Bank 2010). The corresponding figures for drought are estimated at USD 62 million with 25 million people affected (World Bank 2010). India's irrigation sector has also become overwhelmingly dependent on groundwater, with 64% of the 62 million hectares of cropland irrigated with groundwater, as compared to a global average of 38% (Siebert et al. 2010). The importance of groundwater in supporting food production and the livelihoods of millions of smallholders is being undermined by major social and environmental problems due to increasing overexploitation of the resource, which affects around 31% of the country's administrative units (CGWB 2017).

There is a clear need for pragmatic, cost-effective, socially inclusive and scalable solutions to lower the risks from recurrent (and worsening) cycles of floods and droughts (IPCC 2012). This report presents a synthesis of the experience gained from initiating and testing the *Underground Transfer of Floods for Irrigation* (UTFI) approach (as introduced below) in the Indo-Gangetic Plain in India. A multi-scale and interdisciplinary approach is applied that includes regional suitability mapping, site selection, pilot testing, and initial scaling of the approach. In doing so, the study highlights the challenges, gaps and ways forward to help facilitate large-scale uptake of the UTFI approach in India and in appropriate settings elsewhere.

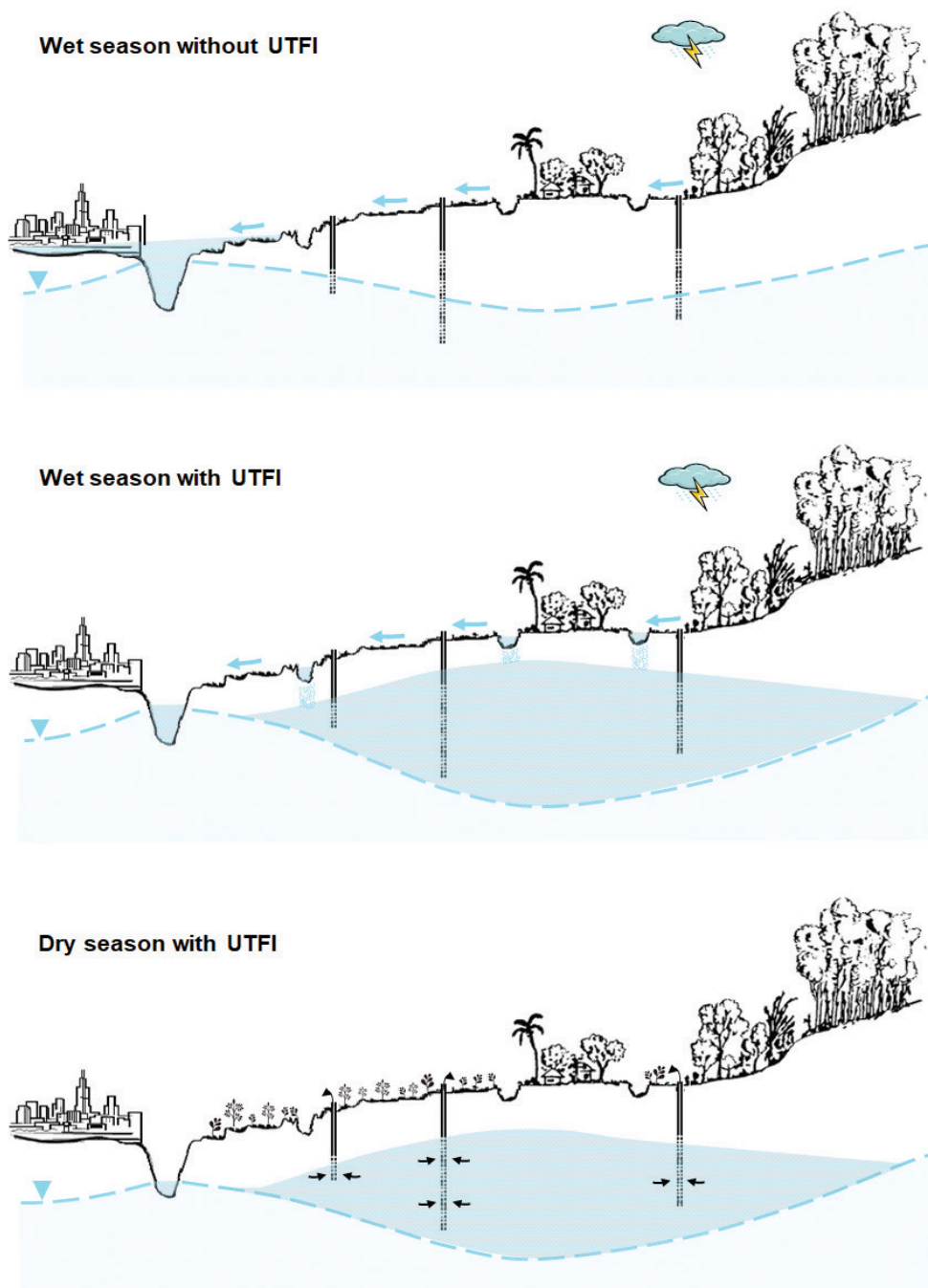
2. Underground Transfer of Floods for Irrigation (UTFI): An overview

Widespread problems of spatiotemporal hydrologic imbalance associated with a surplus or shortage of water are the rationale for a novel water management approach referred to as *Underground Transfer of Floods for Irrigation* (UTFI)¹ (Alam and Pavelic 2020; Gangopadhyay et al. 2018; Pavelic et al. 2015). UTFI involves the targeted capture and recharge of seasonal high flows into depleted aquifers, thus augmenting groundwater storage locally to offset subsequent dry season water scarcity, as well as mitigating local and downstream flooding (Figure 1). Recharge infrastructure is established close to or within the floodplain or upstream of high flood-risk zones, ideally where groundwater storage

¹ Until recently, UTFI was referred to as *Underground Taming of Floods for Irrigation* (e.g., Pavelic et al. 2015).

is depleted or adequate storage capacity is naturally present. The stored recharge water may be recovered to provide supplies for domestic use, livestock watering or irrigation, with a proportion potentially left in situ to enhance ecosystem services such as dry season baseflows to sustain surface water bodies (Chinnasamy et al. 2018).

Figure 1. Schematic representation of a groundwater-dependent, flood-prone landscape with and without UTFI. The figure illustrates that strategic capture and storage of seasonal surface runoff underground can offset downstream flooding while boosting groundwater reserves and enabling enhanced agricultural production.



Source: Alam and Pavelic 2020.

UTFI presents a dedicated way of applying managed aquifer recharge (MAR)² in areas prone to regular and periodic flooding, and where there is extensive groundwater drawdown due to intensive use. UTFI is potentially better suited to addressing more regular, longer-duration floods (i.e., timescales of weeks to months) rather than flash floods that are extreme, irregular and rapid (i.e., hours to days). The magnitude of floods that may be addressed by UTFI requires case-specific analysis that takes into account limits in surface water detention, recharge rates and aquifer storage capacity. It must be noted that under seasonal high-flow conditions, rates of natural groundwater recharge may increase, particularly around intermittently inundated areas (Liu et al. 2016). UTFI may thus add value by further enhancing groundwater recharge within targeted areas of the landscape.

The UTFI approach was introduced in the late 2000s in Thailand (Pavelic et al. 2012), and in the intervening years, the focus has largely been on India, which faces problems of floods, droughts and groundwater depletion. The country has long-standing experience in storing wet-season runoff underground for community water supplies in the more arid regions (Sakthivadivel 2007; Bunsen and Rathod 2016). However, there is still limited experience in the wetter, flood-prone and, sometimes, groundwater-depleted regions such as the Upper Ganga River Basin (Alam and Pavelic 2020).

Experience gained from the implementation of MAR over many decades in many parts of the world supports the need for a comprehensive approach to establishing feasibility (CGWB 2000; Department of Water Affairs 2010; Dillon et al. 2019). Successful undertaking of UTFI ideally requires thoughtful planning and staged development to minimize the potential risks associated with site selection, system design, financing, implementation, stakeholder involvement, environmental impacts, and long-term maintenance and management (Pavelic et al. 2015).

From a risk management perspective, staged implementation of UTFI that covers the following tasks is proposed: (i) regional-scale mapping of UTFI potential; (ii) pilot site selection; (iii) pilot design, testing and evaluation; and (iv) policy formulation and institutional framework for scaling up the approach. This multi-stage/multi-scale sequencing is discussed in detail in the following sections.

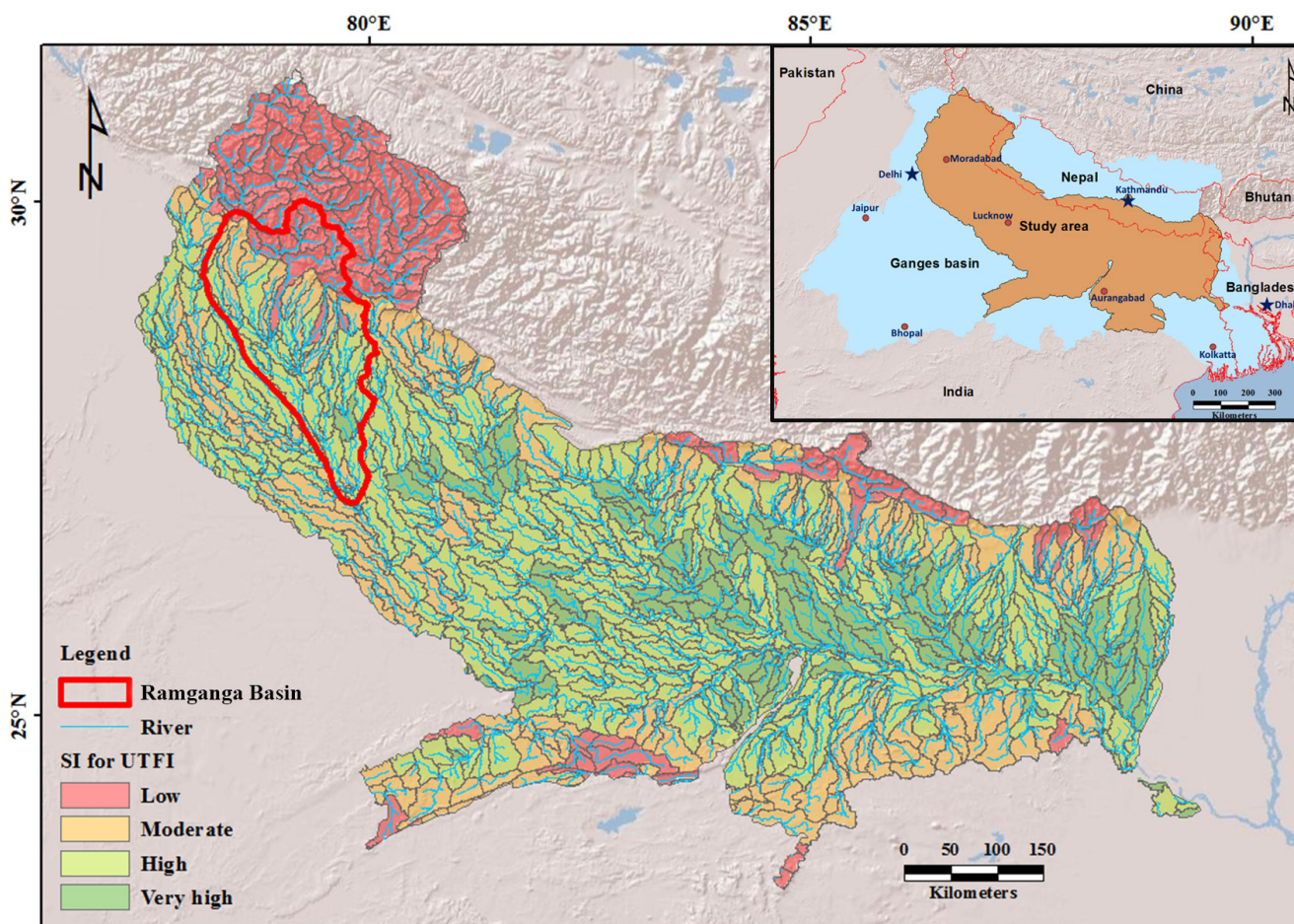
3. Establishing the UTFI pilot in the Ganges River Basin

3.1 Regional-scale mapping of UTFI potential

Implementation of UTFI encompassed pilot demonstration and testing in a suitable area of the Ganges River Basin. The basin is one of the largest and most densely populated regions in the world; home to over 500 million people and covering an area of almost 1.1 million km² across four countries – Bangladesh, China, India and Nepal (Bharati et al. 2016). The basin is subject to regular floods and droughts, and is also heavily impacted by groundwater depletion (Mukherjee et al. 2018). To assess the UTFI potential on a larger scale and help identify a feasible pilot site, maps of the Ganges River Basin, disaggregated to the watershed level (units ranging from ~100 to 1,000 km²), were prepared. Various factors that influence flood frequency and impact, groundwater occurrence, groundwater recharge, storage potential and water demand were considered during the preparation of these maps (Brindha and Pavelic 2016). Data on 10 surface characteristics of the basin (drainage density, population density, surface geology, flood frequency, flood mortality and distribution, flood damage losses, frequency of extreme rainfall, land use, slope and soil type) and two subsurface characteristics (aquifer transmissivity and groundwater level) were collated from different sources and processed by overlaying in a geographic information system (GIS) environment. Results of the analysis of UTFI potential, expressed in terms of a UTFI suitability index (SI), showed that 24% of the inner part of the basin had very high suitability and a further 44% had high suitability (Figure 2). The SI distribution reveals differentiation in suitability across the basin. There was a tendency for lower SI rankings in mountainous and foothill areas towards the margins of the basin. These areas generate high runoff but have low or uncertain groundwater prospects and limited scope for direct use of recharge water, due to the low suitability of land for irrigated agriculture.

² Managed aquifer recharge (MAR) refers to the purposeful recharging of water to suitable aquifers, and the subsequent recovery of this water for human uses or inherent environmental benefits (Dillon et al. 2009).

Figure 2. UTFI suitability index (SI) across the Ganges River Basin determined at the watershed level. The outer margins of the basin that are not prone to floods and droughts, including most areas in Bangladesh (areas shaded in light blue in the inset map), were excluded from the detailed analysis.



Source: Pavelic et al. 2015.

3.2 Pilot site selection

The Ramganga Basin (19,000 km²), a major upstream basin of the Ganges River with high SI, was selected for further investigation (Figure 2). Using basin-level datasets supplemented by available district-level information, a set of local indicators were identified to assist in the process of selecting a suitable pilot site: (i) prevalence of recurrent flooding; (ii) average depth to the water table; (iii) generalized trends in groundwater levels (stable, rising, falling); (iv) size and number of ponds in each village; (v) type of pond ownership³; (vi) distance between the ponds and nearest river or canal; (vii) ease of access (i.e., distance to major road); and (viii) absence of obvious pollution from local or upstream sources (Pavelic et al. 2015). Ponds situated in local depressions with scope for conversion to groundwater recharge structures became the obvious target in the intensively cultivated plains where land availability for UTFI implementation is a major constraint. Historically, ponds were relied upon for domestic and agricultural water supplies. Nowadays, these have largely been replaced by private wells tapping groundwater, due to the availability of appropriate and affordable technologies.

³ Village ponds in India are either private or community owned. The type of pond selected for UTFI implementation would likely affect management arrangements, level of government support, and long-term site access.

Villages within the area were ranked based on the above indicators and field visits were made to the 10 highest-ranking villages. Of these, the top four villages were revisited and a detailed questionnaire was administered to various local and district-level stakeholders to collect information on certain thematic areas: floods, water demand and access, agriculture, livelihoods, socioeconomics, institutions, and general interest in piloting UTFI. On the basis of the final ranking, site visits and detailed consultations, Jiwai Jadid village, situated in Milak block⁴, Rampur district, Uttar Pradesh, with a long-term average annual rainfall of around 900 mm, was selected for piloting (Pavelic et al. 2015).

More details of Jiwai Jadid village and the wider area were collected from baseline studies covering biophysical (IWMI 2017), socioeconomic (LNRMI 2017) and gender (TERI 2017) aspects. These studies show that the village is almost entirely reliant on agriculture for its livelihoods. About 90% of the village area is under cultivation due to good alluvial soils and full irrigation coverage predominantly from tube wells, although an irrigation canal passes through the village. Paddy and wheat are the major crops cultivated during the *kharif* (monsoon – June to October) and *rabi* (winter – November to March) seasons, respectively. Government statistics show that 17% of the households in the village have below poverty line ration cards (TERI 2017). Small and marginal farmers account for 77% of the village households. More than 90% of the households own private tube wells to access water for domestic use and irrigation. While small and moderate floods have occurred over the past decade, there is general consensus that over-abstraction of groundwater is the most critical water issue in the area. Annual abstraction of groundwater in Milak block is around 81% of total recharge (IWMI 2017). Therefore, groundwater resources are categorized as ‘semi-critical’ according to Central Ground Water Board protocols (CGWB 2017). In 2003, one of the six blocks within the district was classified as ‘overexploited’. However, by 2013, this had increased to four blocks.

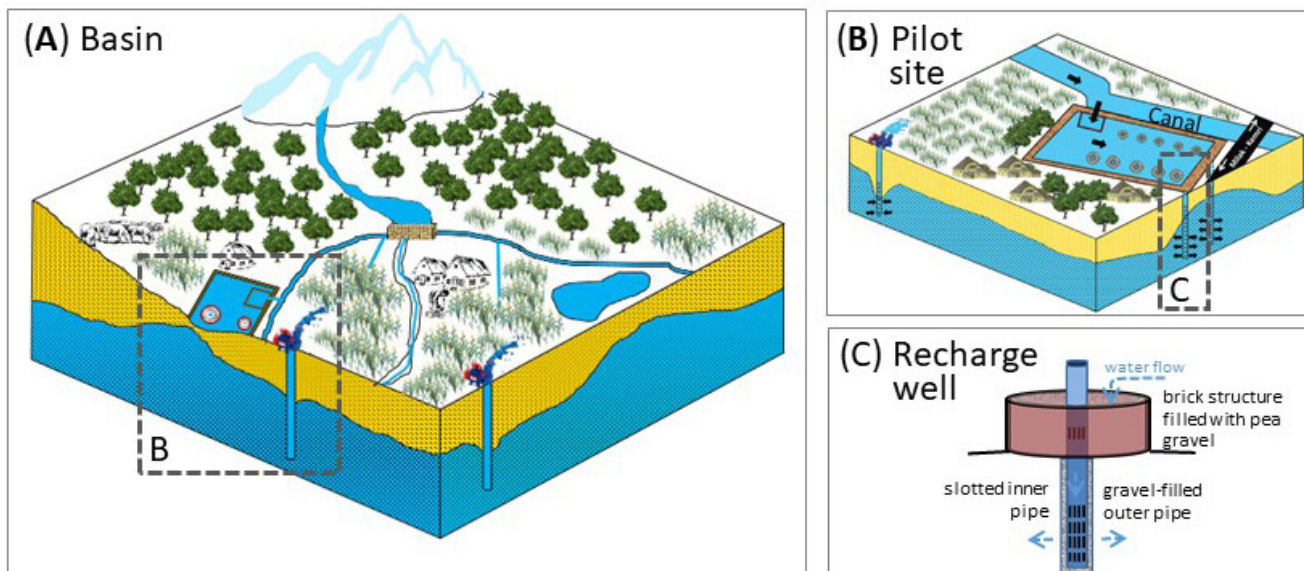
3.3 Pilot design, testing and evaluation

The UTFI pilot was set up in 2015 with a focus on a community pond (75 m × 35 m) that was rehabilitated for the trial (Figure 3). The unconfined upper aquifer targeted for recharge extends to depths of 60 m to 90 m (Tripathi 2009), and is currently the source for much of the groundwater pumped in the area. This aquifer is part of the vast and highly productive Indo-Gangetic Aquifer system. In the pilot area, the predominantly fluvial aquifer systems can attain depths of 1,000 m or more (Saha et al. 2016). An uppermost blanket (approximately 7 m) of low permeability clay soil meant that recharge methods had to reach deeper, more permeable layers. In total, 10 recharge wells were drilled to depths of 25 to 30 m through the base of the pond. The soil strata consists of fine to medium sand layers and clay lenses of Quaternary age. During high flows in the monsoon season, surface water is siphoned into the pond from the adjacent Pilankhar minor canal system, which receives water from a tributary of the Ramganga River. Pond water is treated by sedimentation within the pond itself, and by filtration through a gravel-filled container constructed above the ground around the perforated casing at each of the recharge wells located inside the pond. Finally, the water exits through slots in the casing at the bottom of the well to recharge the aquifer by gravity. Stored water is recovered via existing domestic and irrigation wells in the village. Close monitoring of groundwater levels and quality was carried out by installing nine piezometers to a depth of around 30 m. These were positioned along two transects aligned with the regional groundwater flow direction at distances of 5 m to 700 m downstream from the pond. The recharge rates from the UTFI pond were estimated by monitoring the volumetric changes in the pond, accounting for inflows and outflows (including evaporation losses), and by infiltration testing on the pond floor in the dry season (Alam et al. 2020).

Pilot operations were conducted over three years from 2016 to 2018, following initial short-term testing in 2015. The UTFI system was in operation during the monsoon months of each year when water levels within the canal had risen sufficiently. Desilting of the gravel filter tank beds and pond floor was carried out on an annual basis in 2017 and 2018 when the pond was dry, while desilting of the recharge wells by airlift pumping was carried out only in 2017 (Alam et al. 2020).

⁴ The term ‘block’ refers to a rural administrative unit at the sub-district level.

Figure 3. Schematic representation of the pilot UTFI system at Jiwai Jadid village in Uttar Pradesh, India.



Source: Adapted from Pavelic et al. 2015.

4. Results from pilot testing

4.1 Technical performance and environmental impacts

4.1.1 Water quantity

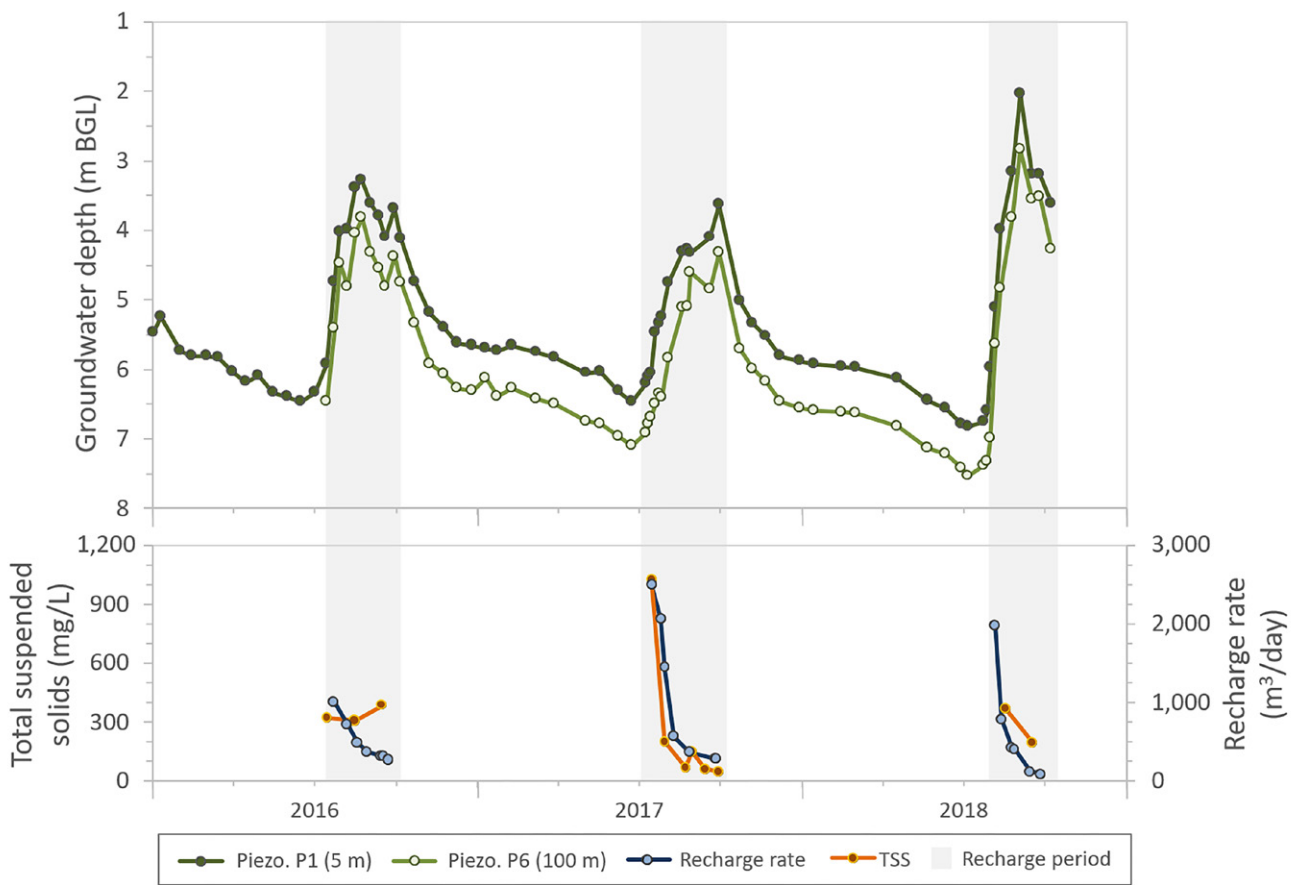
The estimated volumes of water recharged from the pond during the three monsoon seasons ranged from 26,000 m³ to 62,000 m³ over durations ranging from 62 to 85 days each year (Alam et al. 2020). Rainfall amount and intensity were similar in 2016 and 2017, but substantially higher in 2018, resulting in higher intermittent groundwater level buildup (referred to as mounding) (Figure 4). The volumes of water recharged are a function of the aquifer characteristics (e.g., porosity, permeability and water table depth), system design (e.g., well screening depth, number of wells and desilting operations), recharge water quality (e.g., suspended sediment in diverted canal water), and climate (primarily rainfall and evaporation) (Alam et al. 2020). Intra-seasonal declines in recharge rates were observed as a result of: (i) gradual siltation of the gravel filters and wells due to turbid canal and pond water (values of total suspended solids averaged 300 mg/L, but ranged from 50 mg/L to 1,000 mg/L); and (ii) reduced gravity head to drive recharge flow (as the elevation difference between the pond water and groundwater declined due to seasonal rises in groundwater levels across the area) (Alam et al. 2020).

The highest recharge occurred in the year with the lowest rainfall (62,000 × 10³ m³ in 2017, with annual rainfall of 905 mm), and lowest recharge was in the year with the highest rainfall (26,200 m³ in 2018, with annual rainfall of 1,811 mm) (Alam et al. 2020). The latter was explained by a shorter monsoon season with more intense rainfall in 2018 associated with higher groundwater mounding (less driving force for recharge), together with clogging due to high suspended solid concentrations in the recharge water (Figure 4).

The height and extent of groundwater mounding due to recharge was limited due to the high permeability and porosity of the target aquifer, masked by recharge from other sources (local precipitation, canal seepage), and confounded by factors such as pumping from nearby wells during the wet season to meet high crop water demand for paddy rice. Therefore, it is difficult to ascertain mounding attributable to UTFI, but this was estimated from the piezometric difference between P1 and P6 (located

close to, 5 m, and farther away, 100 m, from the pond) to be 0.4 m or less, and most pronounced at the beginning of the season when recharge rates were highest. The limited mounding observed was verified by applying the Hantush analytical model, with an acceptable degree of fit between the modelled and observed data (Alam et al. 2020). The volumes of water recharged through UTFI were estimated by Alam et al. (2020), and this varied from 2% to 4% of the total natural recharge at the village scale (212 ha), which was determined independently. The small contribution of UTFI to the groundwater balance of the village reflects the modest scale of the pilot and is not dependent on performance of the pilot.

Figure 4. Variation in recharge rate, groundwater depth below ground level at piezometers 5 m and 100 m from the pond, and values of total suspended solids in the source (canal and pond) water from 2016 to 2018.



Source: Adapted from Alam et al. 2020.

Notes: Recharge periods are indicated with grey shading. Piezo. = Piezometer; TSS = Total suspended solids; BGL = Below ground level.

4.1.2 Water quality

Monitoring of surface water and groundwater quality was routinely conducted over the duration of the pilot and led to varied results (Table 1). Selected parameters, including pH, fluoride and nitrate, never exceeded national drinking water standards. For both surface water and groundwater, the average values for total dissolved solids, iron and lead were mostly within the standards but with occasional exceedances detected. In contrast, averages for fecal coliforms, arsenic, chromium, mercury and nickel were often above the standards and had high percentages of exceedance. Most parameters that exceeded the standards in surface water and groundwater included samples from two groups of wells: (i) those situated within the area of potential influence of the UTFI pond (i.e., 'near-groundwater'); and (ii) those situated farther away and beyond potential influence of the UTFI pond over the time frame of the pilot (i.e., 'far-groundwater'). Nickel was an exception to this, with surface water and near-groundwater samples having higher concentrations than far-groundwater samples. However, it was the opposite for chromium, with surface water and far-groundwater samples having higher concentrations than near-groundwater samples.

The broad-scale microbial pollution observed, with 75% to 100% exceedance across all sample types, is not surprising as wastewater in the village is poorly managed (e.g., dwellings are fitted with non-sealed pit latrines). The low nitrate values are somewhat surprising in light of the wastewater issues and intensity of agricultural production in the area, but could be explained by potentially good denitrifying clay layers in the upper soil horizon. Further, the values measured lie within the range reported for groundwater samples within Rampur district of 2-48 mg/L (Rajmohan and Amarasinghe 2016). The Ramganga Basin hosts tens of thousands of industries (e.g., producing textiles, leather, steel, paper and pulp, wooden furniture, and sugar), which are deemed to contribute to moderate to high pollution by the Central Pollution Control Board of India (Malyan and Nagpal 2017). There is considerable evidence to show that pollution of soil and water across the basin is widespread (Mukherjee et al. 2018; Paul 2017; Rajmohan and Amarasinghe 2016). Industrial activities upstream of the pilot site could be likely sources of the elevated concentrations of specific metals observed, which are transferred either through groundwater or surface water sources as well as through interactions between both water sources. It is, therefore, likely that microbial and heavy metal contamination was present in groundwater at the pilot site prior to commencing the trial. While the UTFI intervention has also introduced some of these constituents present in surface water into the aquifer, this was often not at levels over and above those already present in groundwater, noting its poor quality even prior to the pilot. This is reflected in the exceedance percentages for far-groundwater samples being of similar magnitude to those for near-groundwater samples for the majority of parameters (Table 1).

4.2 Costs and benefits

The capital cost of implementing the UTFI pilot, excluding research-related costs, is USD 11,500 (INR 800,000). Annual maintenance costs are estimated at USD 1,400 (INR 100,000) (Alam and Pavelic 2020). The average unit cost of water recharged is USD 0.03 (INR 2) per cubic meter. Estimates of the agricultural output attributable to UTFI are based on an approximate average recharge volume of 44,000 m³ per year, of which 75% is withdrawn for agriculture and the remaining 25% assumed to be pumped for domestic uses or retained in the aquifer for supporting environmental flows (Chinnasamy et al. 2018). This quantity of irrigation water is sufficient to irrigate 9.6 hectares of wheat during the *rabi* season with an irrigation water requirement of 350 mm. The benefit-cost ratio for the UTFI pilot is assessed to be 1.34:1, indicating that the benefits, calculated as the income from crops, exceed the upfront and maintenance costs (Zheng et al. Forthcoming)⁵.

⁵ The cost-benefit analysis was undertaken over 20 years with a discount rate of 5%. Benefits are based on the gross returns for *rabi* wheat in Uttar Pradesh for the situation where the production cost is inclusive of all cash and in-kind crop production costs and family labor (CACP 2017, Annex Table 5.1).

Table 1. Concentration and exceedance percentages of water quality parameters in surface water and groundwater in relation to national drinking water standards.

Parameter	Standard ¹	Surface water ²			Near-groundwater ³			Far-groundwater ⁴		
		N ⁵	Concentration ⁶	Exceedance (%) ⁷	N ⁵	Concentration ⁶	Exceedance (%) ⁷	N ⁵	Concentration ⁶	Exceedance (%) ⁷
pH	6.5-8.5	27	7.6±0.45	0	72	7.6±0.4	0	42	7.4±0.4	0
TDS ⁸ (mg/L)	500	27	360±90	7	72	470±130	42	42	450±160	19
Fluoride (mg/L)	1	18	0.23±0.07	0	70	0.32±0.11	0	35	0.24±0.08	0
Nitrate (mg/L)	45	6	13.3±1.3	0	41	11.0±3.2	0	10	3.8±0.5	0
Arsenic (µg/L)	10 / 50 ⁹	8	15.4±8.6	75 / 0	44	13.1±4.6	77 / 0	21	17.0±15.0	62 / 0
Chromium (µg/L)	50	8	38±40	25	44	34±36	18	21	53±55	43
Iron (µg/L)	300	8	201±76	0	44	212±92	7	21	138±119	10
Lead (µg/L)	10	8	5.8±6.0	38	44	2.7±1.4	0	21	4.4±4.6	14
Mercury (µg/L)	1	8	3.9±3.8	88	44	2.4±2.4	91	21	4.0±4.5	67
Nickel (µg/L)	20	8	28±44	13	44	28±43	48	21	20±23	29
Fecal coliform (MPN ¹⁰ /100 mL)	0	8	730±780	100	32	410±580	97	8	110±190	75

¹ Drinking water standards (Bureau of Indian Standards 2012).

² Surface water samples include water from the pond and canal.

³ All wells situated within 100 m of the pond and assumed to be potentially influenced by UTFI groundwater recharge.

⁴ All wells situated beyond 100 m of the pond and assumed to be uninfluenced by UTFI groundwater recharge over the 3 years of the pilot (as calculated from information provided by Saha et al. [2016] and Surinaidu et al. [2016]).

⁵ Total number of samples analyzed for the water source indicated.

⁶ Mean and standard deviation values indicated.

⁷ Percentage of tested samples exceeding the relevant water quality standard.

⁸ TDS = Total dissolved solids.

⁹ The 'acceptable' limit of 10 µg/L and 'maximum permissible' limit of 50 µg/L are both given.

¹⁰ MPN = Most probable number.

Farmers also benefit from UTFI through increases in groundwater levels, which reduce fuel costs for pumping and makes irrigated agriculture more profitable. Most farmers in the village, and across the region more broadly, use diesel-powered centrifugal pumps, which are inefficient and expensive compared with electric pumps (IWMI 2017). The estimated savings in irrigation cost for the entire village, as a result of the UTFI pilot, was estimated to be USD 540 (INR 38,052) per year or USD 2.5 (INR 177) per farmer per year⁶. This aspect was not included in the cost-benefit analysis given above.

4.3 Social and institutional aspects

4.3.1 Stakeholder engagement and perceptions

The pilot required structured engagement with diverse stakeholders. Regular interactions were organized with local communities, government officials, civil society, media and scientific peers through channels that included open days, field visits, workshops, community meetings, focus group discussions and in-depth interviews with different groups (Figure 5). The various stakeholder groups were provided with information on the UTFI concept, implementation process and emerging results. These interactions indicated that stakeholder perceptions regarding UTFI were sometimes mixed. For example, according to some stakeholders within the community, groundwater availability in the dry season had increased. However, others did not agree with this view, and attributed such an increase to the limited scale of the pilot or the timing of operation during the monsoon when recharge rates were already high. These interactions helped the research team to better understand the views of the stakeholders, and consider these views where possible.

4.3.2 Institutional arrangements

The institutional modalities for management of the pilot system evolved, as the barriers to a well-functioning operation were identified and incrementally addressed through monitoring and engagement processes (Reddy et al. 2017, 2020). Initially, operational management was handled by the research team working closely with community leaders and local villagers. Community participation in regular maintenance tasks was enhanced by formally registering the site under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)⁷. The link to MGNREGS was effective in keeping the infrastructure functioning, as farmers were paid by the government to maintain the pond on an annual basis.

Attempts to transition towards more autonomous local management was not straightforward due to the perception of relatively low marginal returns from UTFI for farmers. This was further challenged by the limited preexisting institutional framework within the village. In Jiwai Jadid and surrounding villages in the area, there is an absence of nongovernmental organizations (NGOs), self-help groups, water user associations, or other farm groups. The *Panchayat*⁸ is effectively the only functioning institution (LNRMI 2017). However, neither men (as the primary beneficiaries) nor women were inclined to voluntarily commit to managing the UTFI pilot site over the short or long term⁹. The preference was for ownership of the site to remain with the *Panchayat*, on which the village relies for the provision of capacity, knowledge and financial resources. Men are, however, generally willing to undertake operation and maintenance activities, and even contribute to minor maintenance through MGNREGS. Women are either unwilling or unable to take a more proactive role in the management of the UTFI system (LNRMI 2017; TERI 2017).

⁶ Based on methods reported in Alam and Pavelic (2020), taking into account the average height of the groundwater mound in the village in the monsoon season (as residual mounding was difficult to identify during the dry season), irrigation water applied and the cost of diesel.

⁷ A long-standing national flagship program focused on local natural resource management and livelihood improvement administered by the Ministry of Rural Development, India (<http://www.nrega.ap.gov.in/Nregs/#>).

⁸ A local self-governance system consisting of an elected village council. This is a common local governance structure across South Asia.

⁹ Women do not participate in *Panchayat* meetings. Also, they are not involved in agricultural activities or managing community assets, due to deeply entrenched social and cultural norms.

Figure 5. Photographs from the pilot site - Jiwai Jadid village, Rampur district, Uttar Pradesh, India. (a) initial consultations with the community to assist in site selection; (b) site visit by the Chief Development Officer of Rampur district; (c) field inspection by members of the Central Ground Water Board (CGWB) and National Water Mission; (d) discussion between the research team and the villagers; (e) groundwater level monitoring by research team members; and (f) annual pond maintenance by local villagers under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS).



Photos: International Water Management Institute (IWMI).

With the realization that the local community could not manage the UTFI system independently without external financial and administrative support, the stakeholders involved decided to hand over management to the district authorities, involving block- and village-level officials. The research team carried out training sessions on how to manage the system with these officials and the community. Therefore, since late 2018, the UTFI system was managed by the district administration, which provided support to the village by mobilizing funds from different sources, and channeling them to block development officers of the state government that had the capacity to provide technical and administrative support.

4.4 Simulated impacts of basin-level scaling

Integrated dynamic hydrological modelling was used at the Ramganga Basin scale to explore the effects of widespread distribution of small-scale UTFI interventions on floods and groundwater storage over a historic 11-year period (Chinnasamy et al. 2018). Scenarios capturing between 10% and 50% of the cumulative surface water runoff from the basin were tested. The results showed that declines in groundwater level could not be halted with a capture of 10%; but such declines could be slowed down with a capture of 20%, resulting in an accumulated increase of 3 m in groundwater levels over the simulation period. Increased groundwater levels bring co-benefits through increased baseflow to the Ramganga River in the dry season. The reduction in net basin river discharge would reduce peak discharges, resulting in longer return periods for extreme floods and decreasing the area of inundation. For example, a 20% reduction in basin outflow converted a 15-year flood peak to an 8-year event, and a 5-year peak to 3 years relative to a baseline hydrological regime. The simulations did not take climate change into account.

The modelling shows that the aggregated impact of individual village-level UTFI sites can be significant when implementation occurs on a larger basin scale. On the basis of a mean incremental annual recharge, as achieved during the trial (average of 44,000 m³), it is roughly estimated that 27,000 village ponds would need to be converted to UTFI across the Ramganga Basin to reduce the mean outflow (during July to September) of around 6,000 million cubic meters (Mm³) by 20%. Across Rampur district alone, which covers around 10% of the modelled basin, there are approximately 1,800 ponds, indicating large scope for scaling up the UTFI approach. Additional land allocation may also need to be considered. It should be noted that scaling potential is only tentatively indicated by these parameter values, as extrapolating the results of just one trial pond to the basin scale is associated with a high degree of uncertainty.

5. Lessons from the pilot

The pilot showed that useful volumes of surface water could be transferred to aquifers, which, if replicated widely, could have substantial positive impacts in terms of attenuating floods and increasing general groundwater availability at the basin scale. However, in certain areas with shallow water tables, the volumes recharged annually could be dependent on climate, such that years with high rainfall or years with more intense rainfall events, when flood impacts are most pronounced, coincide with the lowest recharge capacity due to the throttling effect of high groundwater levels on gravity-induced recharge. The effect of annual rainfall on recharge rates carries uncertainty for the design and success of interventions for flood mitigation and groundwater storage where unconfined shallow aquifers are targeted, and this area requires further research. On the other hand, UTFI may have a relatively higher potential in areas with deeper or overexploited aquifers, where the hydraulic driving forces for recharge are expected to be higher and less dependent on rainfall. In addition, it is critical to assess the potential trade-offs between: (i) recharging water to enhance groundwater storage and reduce local flooding; and (ii) the positive impacts of retaining downstream flows for maintaining benefits such as sediment transport, and flushing and dilution of pollutants.

Successful implementation of UTFI is contingent upon not causing undue social or environmental harm. This requires preventing water quality degradation due to recharge of potentially polluted water or undesirable changes in groundwater

chemistry due to UTFI, thereby offsetting the quantitative benefits derived from groundwater recharge. Results from the pilot highlight that the quality of the surface water used for recharge and the ambient groundwater were both less than pristine, with breaches in the national drinking water standards for eight of the 11 parameters monitored in both types of water, and included microbiota and heavy metals. This is taken as symptomatic of environmental issues on a broader scale than the pilot, as previously reported (CWC 2012). It highlights the need for an examination of the effectiveness of catchment-wide land-use planning and pollution control measures within the Ramganga River Basin. From a risk management perspective, the decision to target only the upper aquifer for the pilot, already impacted by anthropogenic and geogenic contamination, was appropriate in this setting. The Indo-Gangetic Plain has abundant groundwater resources. Therefore, careful planning is needed to strictly avoid recharging water that is likely to be of an impaired quality into deeper confined aquifers that are generally of better quality (Saha et al. 2016). Selection of sites for scaling up UTFI should ensure that risks of water pollution are minimized, cognizant of the principles for water quality protection that apply to MAR, as outlined in Dillon et al. (2014).

From an operational perspective, sustainability is contingent upon a high degree of interest and engagement by local communities and government authorities. Engagement during the pilot was moderated on account of several factors. First, expression of the need for radical change in water management was limited, given that the single UTFI system in the pilot site was perceived to increase groundwater levels only marginally. Second, due to the high storage capacity and thickness of the Indo-Gangetic aquifers, drilling and deepening of wells, although costly, remains a viable option for farmers. This, however, could incentivize further UTFI implementation in the future, as the aquifer reaches a depletion level that makes seasonal replenishment through UTFI more attractive. Similarly, while the emerging popularity of highly subsidized solar-powered pumps in India will allow farmers to pump groundwater at a low cost, a scenario where groundwater levels continue to drop below the viable levels of solar pumps (Shah et al. 2018) would potentially increase the interest of village communities in investing and supporting efforts to enhance groundwater recharge in the medium to long term.

6. Progress towards scaling the UTFI approach and future outlook

While UTFI interventions are implemented at the local scale, the socioeconomic and environmental benefits are higher when replicated over larger scales. To achieve the scaling up of co-benefits, there are possible entry points for the uptake of UTFI through multiple sectors, including flood and disaster risk reduction, water and food security (linked to irrigation and groundwater management), climate change adaptation, and rural development. Within the irrigation sector, some progress was made towards scaling up within the piloted Rampur district. UTFI was formally recognized by the Government of India through its introduction in the so-called District Irrigation Plan (DIP) for Rampur district, with budget allocated under the national flagship program *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) (or 'Prime Minister's Irrigation Program'). The plan allows for a total of 50 sites with an indicative capital investment of USD 1.2 million (INR 75 million) over a time frame of 5 to 7 years. The geographic focus is on the administrative blocks categorized as having the most critically overexploited groundwater resources. Including UTFI in the DIP for Rampur district was facilitated through the support provided by high-level officials within the district, and by close engagement of the project with the district nodal agency of PMKSY.

UTFI is still not a widely applied technology, and lacks broad awareness and adoption by decision-makers and other professionals within relevant fields. The institutional arrangements applied are sufficient for the limited development to date, but need to evolve into a more systematic and programmatic approach over the longer term to achieve replication and sustainability of interventions (Reddy et al. 2020). Effective mainstreaming of UTFI into policies and planning hinges upon its successful piloting and upscaling, as well as its convergence with broader policies and development programs taken forward by national, state and local governments, NGOs, and the private sector. Some of the most prospective entry points for the uptake of UTFI into existing policies and programs in the Indian context include the following:

- ‘Sustainable groundwater management’ as a focused thematic priority area of the government linked to various relevant national programs, such as the *Atal Bhujal Yojana* (ABHY) - National Groundwater Management Improvement Program,¹⁰ National Aquifer Mapping and Management Programme, Master Plan for Artificial Recharge to Ground Water, and others.¹¹
- Integrated Watershed Management Program (IWMP) implemented under PMKSY (watershed development component).¹²
- MGNREGS administered by the Ministry of Rural Development.¹³
- Corporate Social Responsibility (CSR)-related activities from the private sector driven by mandated laws to invest profits in critical social development needs.¹⁴

There is scope for implementing UTFI across large tracts of India with high inter-seasonal rainfall variability, and a high dependence on groundwater and some level of depletion of this resource. There is also scope for implementing UTFI in other countries and regions, as suggested by the global mapping of potential and economic analyses conducted by Alam and Pavelic (2020). This information offers a good starting point for screening and initial decision-making by policy makers and practitioners on local and basin-wide UTFI feasibility. Scaling up UTFI hinges upon continued research. Further research efforts from the Indian context should establish feasibility through additional pilot/demonstration sites across more diverse agroecological and hydrogeological conditions. With advancements in both research and development, UTFI may begin to reach its potential as a practical and effective way for rural communities to respond locally to floods, droughts and groundwater overexploitation.

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¹⁰ <https://projects.worldbank.org/en/projects-operations/project-detail/P158119>

¹¹ <http://cgwb.gov.in/>

¹² <https://pmksy.gov.in/>

¹³ <https://www.nrega.nic.in/>

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