

Managed aquifer recharge applications for climate adaptation in developing countries: Mounting evidence, abundant potential

Key messages

- **Flood reduction, groundwater level restoration and sustained agricultural productivity:** In Uttar Pradesh, India, the Underground Transfer of Floods for Irrigation (UTFI) approach to MAR has increased groundwater storage by over 25,000 m³ per year at the pilot scale, and has since been adopted in hundreds of villages in the Ramganga Basin.
- **Water security improvement and gender equality:** In Zimbabwe's Shashe catchment, sand dams have improved water security by extending water availability by more than 4 months annually and reduced the daily burden of water collection on women, providing them with time to engage in other livelihood activities.
- **Flood mitigation and urban water supply improvement:** In Islamabad, Pakistan, the installation of 100 MAR sites has fostered recharge of stormwater to mitigate flood risk, raise groundwater levels by over 3 meters and improve water quality.
- **Climate adaptation in agriculture:** In Vietnam's Central Highlands, MAR has alleviated seasonal water shortages for coffee farmers by capturing monsoonal runoff for groundwater recharge, satisfying up to one-third of irrigation water needs during critical dry season months.

Managed aquifer recharge (MAR) is a well-established technique that enhances groundwater storage during wet periods, thereby making water available during dry periods. Four case studies from Africa and Asia reviewed in this brief demonstrate the **concrete and sustained benefits** derived from MAR.

Global assessments reveal a vast potential with over 15 million square kilometers (11% of the world's land area) potentially suitable for MAR. Given the substantial benefits and opportunities MAR offers, it is essential for policymakers and practitioners to **accelerate its implementation in developing countries** as a tool for enhancing climate resilience. The evidence and guidance provided in this brief and related documents offer valuable support for this effort. Concrete steps are outlined to help developing countries lay the groundwork for successful MAR implementation, thereby strengthening their climate adaptation strategies.



Singan Khera recharge site, Rampur district, Uttar Pradesh, India, established under the Mission Amrit Sarovar (photo: IWMI).

Introduction

Extreme weather events are becoming more frequent and intense, affecting water supplies for drinking, sanitation and farming in many regions. Both droughts and floods result in significant human and economic consequences. The World Meteorological Organization (WMO) estimates that over the past 50 years, the total economic costs from weather, climate and water-related disasters reached USD 4.3 trillion, with a five-fold increase in the number of such events over this period. This highlights the pressing need for water management to enable more effective climate adaptation.

Innovative water management practices, such as managed aquifer recharge (MAR), offer tangible steps towards addressing uncertainty and variability in supply, and for enhancing water security. MAR involves the intentional recharge of water to aquifers for subsequent recovery for productive use or environmental benefit. MAR can also mitigate floods and improve water quality in local streams and coastal waters. In coastal as well as inland areas, MAR can maintain groundwater quality by controlling saltwater intrusion and diluting high-salinity groundwater. However, MAR can increase the risk of groundwater pollution through the use of low-quality surface water for recharge, if not properly managed.

MAR utilizes a wide range of methods to store water in aquifers (Figure 1). Depending on the local hydrogeological conditions and land availability, open infiltration ponds or tanks can be used to recharge shallow unconfined aquifers, while recharge wells are necessary to target deeper aquifers. Sound technical

design is crucial to ensure MAR systems operate effectively over the long term.

Global assessments show that areas with high potential for MAR cover about 11% of the world's land area, home to half of the global population and 40% of croplands (Alam and Pavelic 2020). South Asia, East Asia, Southeast Asia and sub-Saharan Africa are highlighted as regions with high potential for MAR. Current implementation of MAR, however, falls short of its potential. Although MAR is utilized in over 60 countries, there are less than 60 documented cases in Africa and less than 200 in Asia (Alam and Pavelic 2020; Ebrahim et al. 2020). Evidence of MAR implementation in developing countries remains scant due, in part, to lack of awareness of this approach rather than lack of potential. To raise awareness of the benefits of MAR in developing countries, this brief presents evidence of MAR implementation in four diverse hydrogeological and socioeconomic contexts across Asia and Africa, where the International Water Management Institute (IWMI) has implemented MAR projects together with its partners (Figure 2).

The four case studies apply MAR to achieve the following:

- Address multiple water risks in the Ramganga Basin, India - Underground Transfer of Floods for Irrigation (UTFI) in the humid subtropics
- Enhance water security in the Shashe catchment, Zimbabwe - Sand dams to enhance water security in semi-arid areas
- Boost groundwater storage in Islamabad, Pakistan - Rainwater harvesting for groundwater recharge in urban environments
- Manage water scarcity in the Central Highlands, Vietnam - Farmers using MAR to sustain coffee production

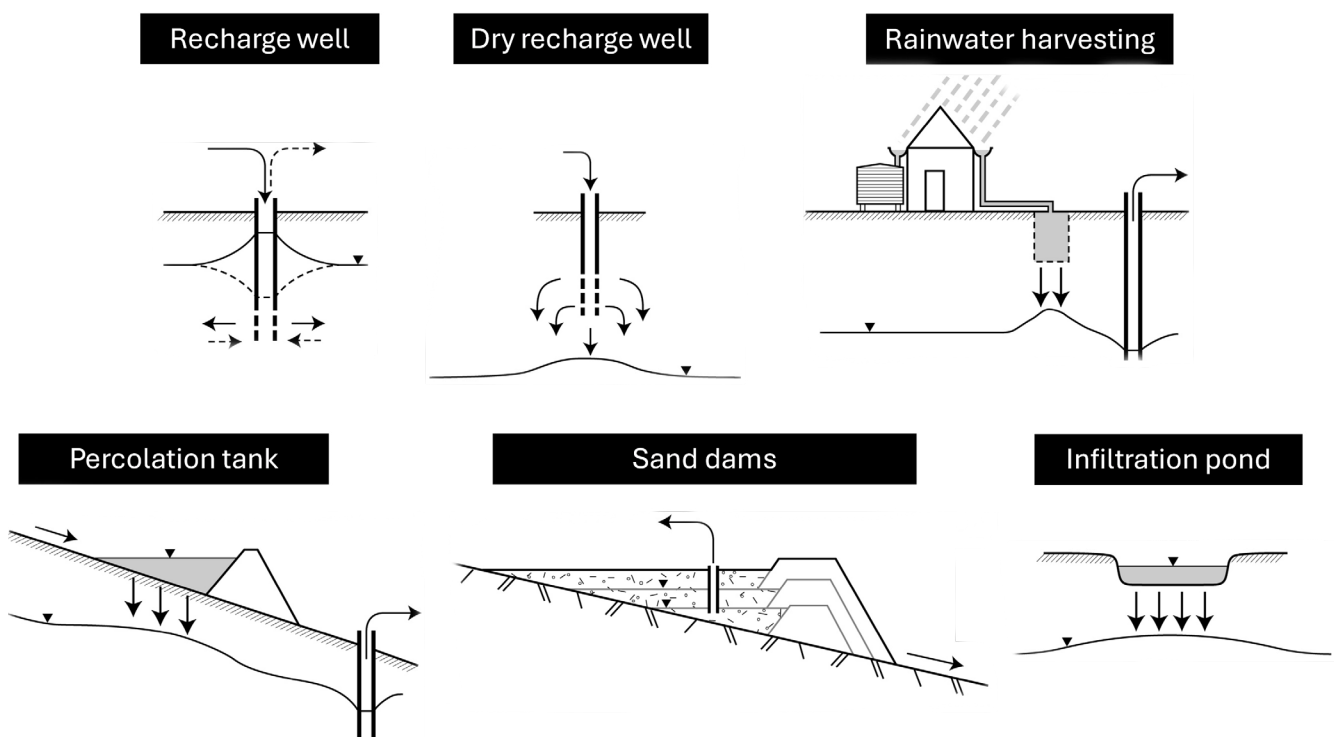


Figure 1. Schematic of alternative managed aquifer recharge methods.

Source: Modified from Dillon 2005 (Dillon, P.J. 2005. Future management of aquifer recharge. *Hydrogeology Journal* 13(1):313-316. <https://doi.org/10.1007/s10040-004-0413-6>)

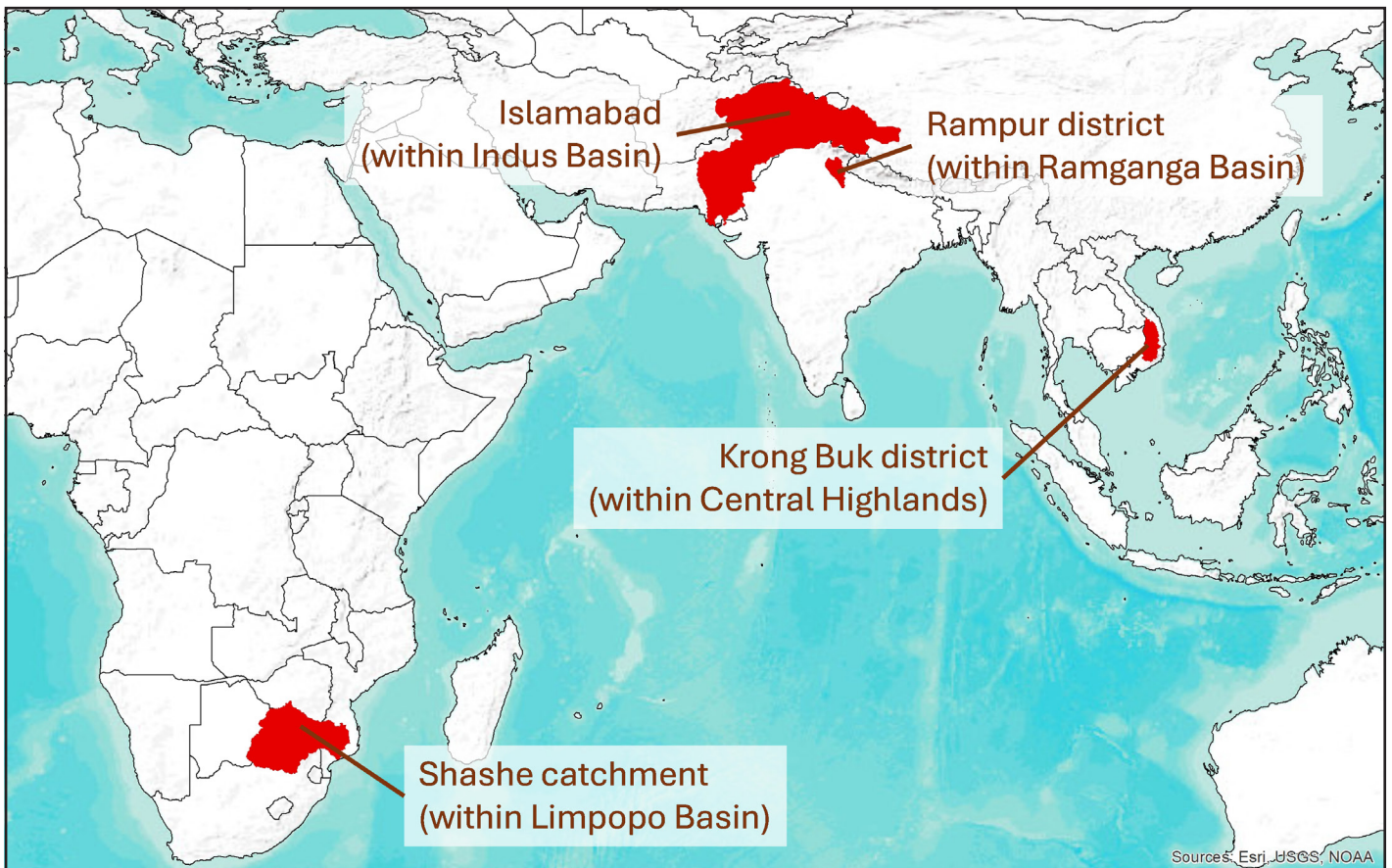


Figure 2. Location of MAR case study sites.

Underground Transfer of Floods for Irrigation (UTFI) in the humid subtropics: Case study from India

The Underground Transfer of Floods for Irrigation (UTFI) approach involves the utilization of excess runoff from fields, rivers or canals to recharge groundwater systems via village ponds, small dams or open wells (Figure 3). This approach can be practiced in locations where these excess flows pose a high flood risk. The recharged groundwater is then recovered using existing nearby wells for irrigation and domestic use or retained to increase water availability during the dry season. The benefits of UTFI are maximized when individual community level interventions are scaled within a watershed or catchment to capitalize on upstream and downstream linkages.

In India, an IWMI-led UTFI pilot was established using a rehabilitated community pond situated next to an irrigation canal. Ten recharge wells were drilled through the base of the pond to reach permeable layers, allowing surface water to recharge the aquifer under gravity after being treated by sedimentation and filtration. During 3 years of piloting, the volumes of canal

water recharged each year varied from 26,000 m³ to 62,000 m³. Recharge rates were found to be dependent on rainfall patterns, groundwater levels and the concentration of particulate matter in the source water (Alam et al. 2020). The UTFI approach did not negatively affect groundwater quality, which was already compromised by heavy metal and bacterial concentrations above the Indian drinking water standards (Jha et al. 2021). The estimated benefits, including increased groundwater availability for agriculture and reduced pumping costs, resulted in a positive benefit-cost ratio of 1.3:1. The local community were generally supportive of MAR and were actively involved in maintenance of the system (Ratna Reddy et al. 2020).

Over the course of the piloting, UTFI was integrated into district-level irrigation plans under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) program. UTFI has since gained more systematic institutional support through integration into national policies and development programs. Based on the success of the piloting, IWMI, through the CGIAR Initiative on NEXUS Gains, is currently supporting the Government of India to better implement a national water conservation program (Mission Amrit Sarovar), and infrastructure for MAR has been put in place in more than 400 villages across the Ramganga Basin.



Figure 3. 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).

Sand dams to enhance water security in semi-arid areas: Case study from Zimbabwe

Sand dams are a promising yet underutilized form of small-scale MAR that can help rural communities build resilience to drought. Sand dams are essentially barriers constructed in ephemeral sand rivers and are made from concrete or masonry materials to enable the accumulation of sand behind the barrier. This, in turn, allows the capture and storage of water within the pore spaces of the accumulated deposits during the wet season (Figure 4). Water is typically abstracted from a shallow well within the dam using a hand pump for domestic purposes, but depending on water availability, can also be used for livelihood-generating activities such as vegetable gardening and brickmaking.

To help understand the potential role of sand dams, an assessment was carried out to identify the impacts of 20 sand dams in 19 communities in the Zimbabwean portion of the Shashe catchment, with a focus on aspects related to climate resilience (Lazurko et al. 2024). The results showed that sand dams significantly improved local water availability. Water was available for more than 4 additional months a year, from a mean of less than 7 months before sand dam construction to about 11 months after construction. The extended duration applied even to drought years. This improvement greatly reduces pressure on communities to adopt restrictive drought-response measures. Sand dams also generate additional ecological and social benefits such as diversification of livelihood activities, improved health and hygiene, and reduced erosion in the surrounding area due to increased vegetation. The provision of safe water as well as the reduction in the distance to water sources further lessens the burden on women and provides them with time to engage in other livelihood activities.

Sand dams are, however, not without risks. The quality of the water abstracted from the sand dam sites may not be adequate and long-term water quality testing is required to determine whether sand dams are effective in filtering out minerals and other potential contaminants. Unlike other small water infrastructure constructed in rural areas, sand dams require periodic maintenance. In some parts of the catchment, the geological characteristics do not allow for sand dam construction. This is particularly problematic for those areas where boreholes dry up during the dry season. Overall, however, sand dams have significant potential and comprise one key option in integrated water storage management.



Figure 4. IWMI and Dabane Trust carrying out sand dam monitoring in Gwanda, Zimbabwe (photo: Dabane Trust).

Rainwater harvesting for groundwater recharge in urban environments: Case study from Pakistan

IWMI's work on MAR in Pakistan started with a demonstration trial for capturing stormwater and using it for groundwater recharge in an urban setting. In collaboration with the Pakistan Council of Research in Water Resources (PCRWR), and with support from WaterAid, IWMI designed and demonstrated a model of MAR at Kachnar Park, Islamabad (Figure 5). At this site, surface runoff generated from so-called 'clean environments' (i.e., rooftops, parks, greenbelts) is collected within a small pond where it is recharged through injection wells following pretreatment by sedimentation (within a pond) and finally filtered through soil layers.

The groundwater recharge site at Kachnar Park is the first-ever, fully instrumented site in Pakistan where the quantity and quality of groundwater recharge are monitored by automated instrumentation that provides real-time information on changes in groundwater and salinity levels. MAR testing at the site was a success. As a result of a 72 mm rainfall event in June 2022, a rise in groundwater level of about 10 m was recorded (from 38

to 28 meters below ground level), and groundwater quality had also improved, with electrical conductivity decreasing from 390 $\mu\text{S}/\text{cm}$ to 230 $\mu\text{S}/\text{cm}$.

Based on the success of the first trial, the Capital Development Authority (CDA), Islamabad, initiated the installation of 100 such MAR systems across the city through government funding with the technical design developed by IWMI. During the monsoon season (January 2022 to August 2023), groundwater recharge of about 329,000 m^3 has been achieved from these 100 sites, which has contributed towards aquifer replenishment and control of urban flooding. Monitoring at four piezometric stations indicates an overall rise of about 3.4 m in groundwater level. Moreover, improvement in groundwater quality has also been recorded due to the recharge of fresh water.

Despite there being a high potential for establishing MAR sites in the major cities of Pakistan, uptake of the approach has been slow. Based on the successful extension and wider acceptance of the MAR model for Islamabad, IWMI is collaborating with the provincial (state) governments to establish fully instrumented MAR sites in cities within these provinces to provide scientific evidence for the uptake of groundwater recharge initiatives at the national scale.



Figure 5. Groundwater recharge site at Kachnar Park, Islamabad, Pakistan (photo: Amjad Jamal/IWMI).

Farmers using MAR to sustain coffee production: Case study from Vietnam

In the Central Highlands of Vietnam, five small-scale pilot MAR interventions were set up to capture runoff from fields, rooftops and other paved surfaces and store this water in shallow volcanic aquifers via shallow irrigation wells which are dormant during the monsoon season (Pavelic et al. 2022) (Figure 6). Since much of the infrastructure is already in place, and the recharge process relies on a simple pretreatment process and gravity-fed infiltration, the investment costs are reasonable. The costs for installing individual MAR systems can be as low as USD 200.

MAR sites that perform well can store up to 500 m³ of water. Groundwater recharge performance was nonetheless found to be dependent on the type of water sourced, amount of rainfall during an year, and the extent of site maintenance provided. Sites using the cleanest water drawn from rooftops had the highest performance, while sites using highly turbid runoff water from unpaved roads had the lowest performance. The volumes of water recharged are sufficient to provide for one of the three rounds of irrigation needed during the dry season. Detailed water quality sampling indicated that there was no measured parameter that presents a major concern for irrigation.

MAR generates benefits that extend beyond the farm boundary. Much of the water recharged to the aquifer is unlikely to be directly recoverable from the well that was used for recharge during the dry season, due to the small size of the recharge water ‘body’ (Figure 1) relative to the high groundwater velocities resulting from steep hydraulic gradients. Water is, however, retained within the watershed (within distances of tens to hundreds of meters from the source of recharge), providing potential for the community to benefit from improved water security for irrigation, domestic use and dry season baseflow.

MAR received endorsement from the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MoNRE), in Vietnam, as well as the private sector as an agricultural extension tool for climate adaptation; an important milestone to enable wider adoption. MAR interventions were initially implemented by IWMI and Hanns R. Neumann Stiftung with the support of Nestlé, the Swiss Agency for Development and Cooperation (SDC) and CGIAR, working together with various government agencies and local farmers. Building on the lessons learned from the initial piloting, a new phase of the project is starting with IWMI working with the Western Highlands Agriculture & Forestry Science Institute (WASI) and Dong-A University with support from the Global EbA Fund in the implementation of a larger cluster of new MAR interventions to increase the cumulative impact of piloting.



Figure 6. A MAR pilot site in Krong Buk district, Dak Lak province, Vietnam (*photo*: Paul Pavelic/IWMI).

Concrete next steps

Some of the concrete steps to facilitate MAR implementation include the following:

- 1. Developing national strategies for MAR.** Countries identified with high potential for MAR are well-positioned to develop a comprehensive national strategy. This strategy should adopt a multifaceted approach, addressing technical, financial, social, environmental and regulatory dimensions. An iterative process that incorporates insights from the key elements outlined below is essential for successful implementation.
- 2. Conducting feasibility studies in high-potential areas.** Feasibility studies are a crucial first step in evaluating the technical, economic and environmental viability of MAR at a specific site. These studies assess the suitability of the location by examining potential water sources, aquifer conditions and infrastructure needs. The insights gained can inform the decision to advance to the piloting stage and guide the design of MAR systems that are tailored to local hydrogeological conditions, water demand and community expectations.
- 3. Piloting MAR projects.** Piloting is essential for validating MAR concepts, assessing system performance and addressing site-specific challenges. It generates critical data for models that help optimize designs, ensuring that projects are scaled up effectively, sustainably and economically. Involving local communities in planning and decision-making is crucial for the success of these projects.
- 4. Developing local capacity.** Training local professionals in MAR techniques and management is an important investment in the long-term sustainability of MAR projects. Capacity building can be achieved through targeted short courses, on-the-job training and international collaboration to support the design, implementation and monitoring of these projects. Embedding these activities within feasibility assessments and piloting activities ensures that capacity is built in practical, impactful ways. Workshops, training sessions and open days can be organized for policymakers, water managers, local communities and the media to foster a shared understanding of MAR, its benefits and implementation. Promoting research activities will support students and young professionals, driving innovation in MAR technologies and methods that address current and future needs.

Sources

This Water Policy Brief is largely adapted from the following sources:

- Alam, M.F.; Pavelic P. 2020. *Underground Transfer of Floods for Irrigation (UTFI): Exploring potential at the global scale*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 58p. (IWMI Research Report 176). doi: <https://doi.org/10.5337/2020.204>
- Alam, M.F.; Pavelic, P.; Sharma, N.; Sikka, A.K. 2020. Managed aquifer recharge of monsoon runoff using village ponds: Performance assessment of a pilot trial in the Ramganga Basin, India. *Water* 12(4):1028. <https://doi.org/10.3390/w12041028>
- Ebrahim, G.Y.; Lautze, J.F.; Villholth, K.G. 2020. Managed aquifer recharge in Africa: Taking stock and looking forward. *Water* 12(7):1844. <https://doi.org/10.3390/w12071844> (Special issue: Managed Aquifer Recharge for Water Resilience).
- Jha, S.K.; Mishra, V.K.; Verma, C.L.; Sharma, N.; Sikka, A.K.; Pavelic, P.; Sharma, P.C.; Kant, L.; Sharma, B.R. 2021. Groundwater quality concern for wider adaptability of novel modes of managed aquifer recharge (MAR) in the Ganges Basin, India. *Agricultural Water Management* 246:106659. doi: <https://doi.org/10.1016/j.agwat.2020.106659>
- Lazurko, A.; Lautze, J.; Hussey, S.; Muzarabani, C.; Ngwenya, N.; Ebrahim, G. 2024. Assessing sand dams for contributions to local water security and drought resilience in the semi-arid eastern Shashe catchment, Zimbabwe. *Regional Environmental Change* 24:36. <https://doi.org/10.1007/s10113-024-02201-y>
- Pavelic, P.; Hoanh, C.T.; D'haeze, D.; Vinh, B.N.; Viossanges, M.; Chung, D.T.; Dat, L.Q.; Ross, A. 2022. Evaluation of managed aquifer recharge in the Central Highlands of Vietnam. *Journal of Hydrology: Regional Studies* 44: 101257. <https://doi.org/10.1016/j.ejrh.2022.101257>
- Pavelic, P.; Sikka, A.K.; Alam, M.F.; Sharma, B.R.; Muthuwatta, L.; Eriyagama, N.; Villholth, K.G.; Shalsi, S.; Mishra, V.K.; Jha, S.K.; Verma, C.L.; Sharma, N.; Reddy, V.R.; Rout, S.K.; Kant, L.; Govindan, M.; Gangopadhyay, P.; Brindha, K.; Chinnasamy, P.; Smakhtin, V. 2021. *Utilizing floodwaters for recharging depleted aquifers and sustaining irrigation: Lessons from multi-scale assessments in the Ganges River Basin, India*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 20p. (Groundwater Solutions Initiative for Policy and Practice (GRIPP) Case Profile Series 04). <https://doi.org/10.5337/2021.200>
- Ratna Reddy, V.; Rout, S.K.; Shalsi, S.; Pavelic, P.; Ross, A. 2020. Managing underground transfer of floods for irrigation: A case study from the Ramganga basin, India. *Journal of Hydrology* 583: 124518. <https://doi.org/10.1016/j.jhydrol.2019.124518>

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