TECHNICAL BRIEF

Strengthening Managed Aquifer Recharge Investments through Evidence: Insights from the Ramganga Basin in India

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Front cover photo: Staff gauge in a pond at Rampur in Uttar Pradesh, India. (*photo:* Tanmoy Bhaduri/IWMI)
Back cover photo: Recharge pit in a pond at Rampur in Uttar Pradesh, India (*photo*: Tanmoy Bhaduri/IWMI)

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Background

Groundwater underpins India's food and water security, supplying irrigation to two-thirds of its farmland and meeting about 85% of drinking water needs. It fueled the Green Revolution, boosting food production and reducing poverty. However, intensive use has led to unsustainable extraction, with around 20% of India's groundwater now at overexploited or critical levels of development.

To tackle groundwater depletion and strengthen water security, government agencies, NGOs, and private actors are increasingly promoting Managed Aquifer Recharge (MAR) interventions. MAR intentionally recharges aquifers during surface water surplus periods through purpose-built structures, enhancing groundwater storage during the monsoon to support dry season irrigation and reduce long-term groundwater decline. India's ambitious Master Plan for Artificial Recharge[1] targets 14 BCM of recharge through 14 million structures, implemented via initiatives such as Amrit Sarovar, Jal Shakti Abhiyan, Jal Sanchay Jan Sahbhagita (JSJB), NREGS, and various state groundwater programs. Collectively, they have resulted in thousands of recharge structures (ponds, check dams, and percolation tanks) being implemented across the region[2].

The monitoring, management and evaluation of recharge structures remain limited. This policy brief draws on field assessments of representative groundwater-stressed Ramganga basin (Figure 1), in the Ganges basin, to generate evidence on the hydrologic performance and effectiveness of MAR investments. The findings aim to guide future design, operational management, and investment decisions under development programs, supporting more sustainable groundwater recharge and improved water security in the Ganges basin and beyond.

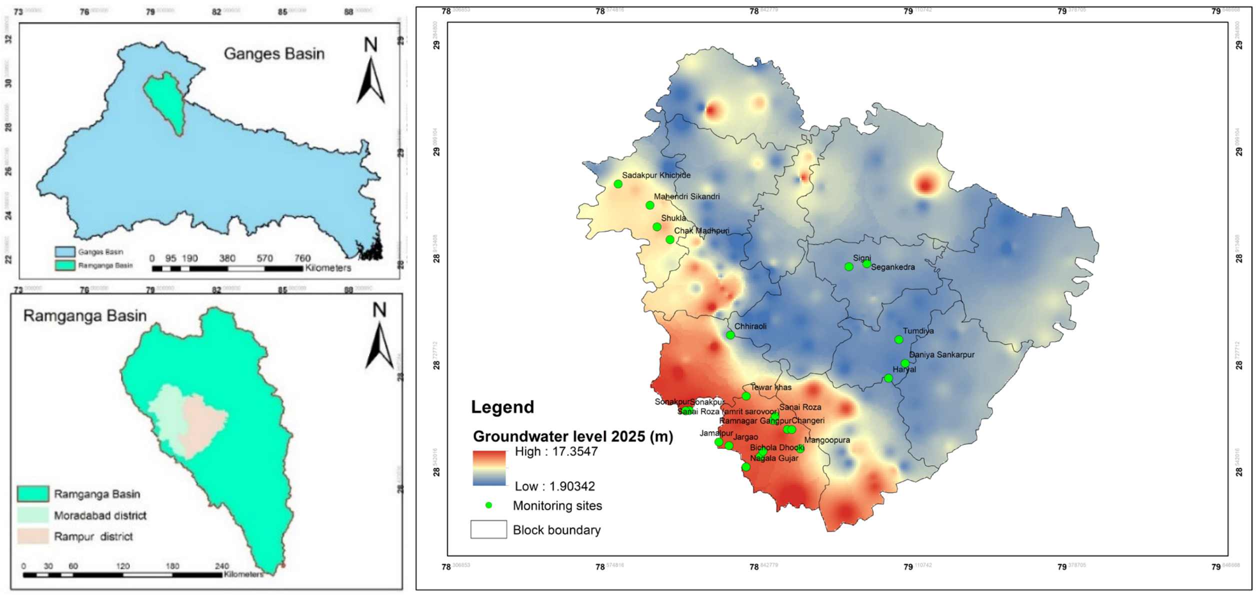


Figure 1. Location of the Ganges River basin (top left); Ramganga basin (bottom left) pond monitoring locations across Rampur and Moradabad districts (right) (*Source:* author's creation)

[1] CGWB, 2021. https://cgwb.gov.in/cgwbpnm/public/uploads/documents/168613326251844776file.pdf

[2] Alam et al. (2025). Assessing the contribution of managed aquifer recharge programs on groundwater storage in the Ramganga basin. Groundwater for Sustainable Development 30, 101486. https://doi.org/10.1016/j.gsd.2025.101486

Participatory Monitoring of Recharge Performance

The study was conducted in close coordination with government line departments and local officials across Rampur and Moradabad districts, Uttar Pradesh. Stakeholder consultations were carried out to gain institutional endorsement followed by joint field visits to identify ponds for monitoring. Based on the datasets of existing ponds in the districts, 147 ponds were surveyed, focusing on the south-western part of the two districts where groundwater levels were relatively deeper. Field data were collected using a structured questionnaire capturing biophysical and socio-economic parameters, including pond area, depth, ownership, use, accessibility, groundwater depth, and community interest. A suitability framework was developed to identify ponds for monitoring, from which, 23 representative sites were selected for detailed monitoring ensuring a mix of site types that included: (1) control (ponds which had not been rejuvenated); (2) repurposed (ponds which had been rejuvenated with de-siltation and embankment); and (3) repurposed with recharge wells installed (Figure 2).

Figure 2. Representative photos of the a) Control pond, b) Repurposed pond, c) Repurposed pond with recharge wells and d) Repurposed pond with recharge pits (*photo*: IWMI)

At selected sites, staff gauges were installed to monitor water levels, and topographical surveys were conducted to develop stage–volume and stage–area relationships that are used to analyse volumetric recharge from these ponds. Participatory monitoring was promoted by training local volunteers to collect and transmit water level data via mobile applications, ensuring continuous, community-driven data collection across monsoon and post-monsoon seasons. Recharge estimation combined water balance and water level fluctuation methods, accounting for evapotranspiration losses for both. In 2025, four monitoring sites were additionally equipped with recharge pits and piezometers to assess the increase in recharge performance compared to baseline conditions (during 2023 and 2024). Total 15 sites were monitored in 2023, 8 more sites were added in 2024 whereas in 5 sites monitoring was stopped, due to operational reasons, in 2025.

Figure 3. Workflow for the study, commencing from stakeholder consultation through to data analysis (*Source*: author's creation)

Recharge Performance of Ponds

- **Recharge volumes**

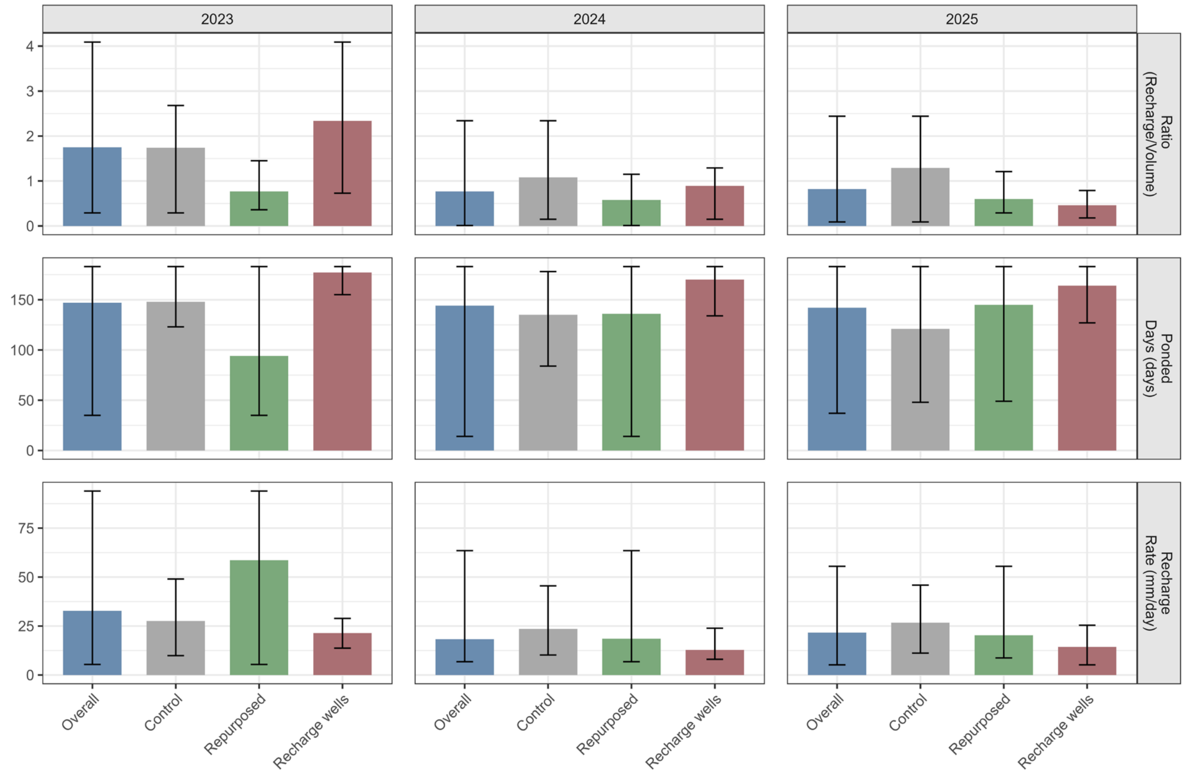
On average across all sites, the recharge performance was suboptimal. The ratio of recharge volume to pond storage was highest in 2023 (1.75 times) but dropped to about 0.8 times in 2024 and 2025, indicating lower recharge efficiency over time (Figure 3). Among site types, recharge well sites initially performed best with 2.34 times storage recharge in 2023 but declined sharply to 0.90 and 0.46 in 2024 and 2025, respectively. Control ponds followed a similar pattern but with a less steep decline (1.74 → 0.92 → 1.29). Repurposed ponds consistently showed the lowest recharge ratios (0.77 → 0.63 → 0.60). Compared to the UTFI pilot in the same area[3], where recharge was 5–12 times the pond storage, these values are relatively low.

Recharge volume depends on two factors — how long water remains in the pond and how fast it infiltrates.

- **Water availability in the ponds**

Across all sites, the average ponding remained fairly stable at around 140 days per season (median 173 days), indicating generally adequate water availability (Figure 3). Control ponds, however, showed a slight decline in ponded days during 2024 and 2025, likely reflecting delayed or reduced rainfall in those years (rainfall: *1424 mm* in 2023, *999 mm* in 2024 and *944 mm in 2025*). In contrast, recharge well sites—particularly in Rampur—recorded the longest ponded durations (>160 days annually), supported by better inlet and outlet management. Even so, these sites experienced a marginal reduction in ponded days under lower rainfall conditions in years 2024 and 2025.

Despite the overall adequate water availability, four out of 23 monitored ponds faced persistent constraints. Two ponds remained completely dry, one received water only through pumped groundwater, and another retained water for less than a month, with depths rarely exceeding 0.2 m. These exceptions highlight that even under favorable rainfall and runoff conditions, poor siting or inadequate inlet design can significantly limit pond performance and reduce recharge potential.



[3] Alam et al. (2020). Managed Aquifer Recharge of Monsoon Runoff Using Village Ponds: Performance Assessment of a Pilot Trial in the Ramganga Basin, India 12(4), 19. https://doi.org/10.3390/w12041028

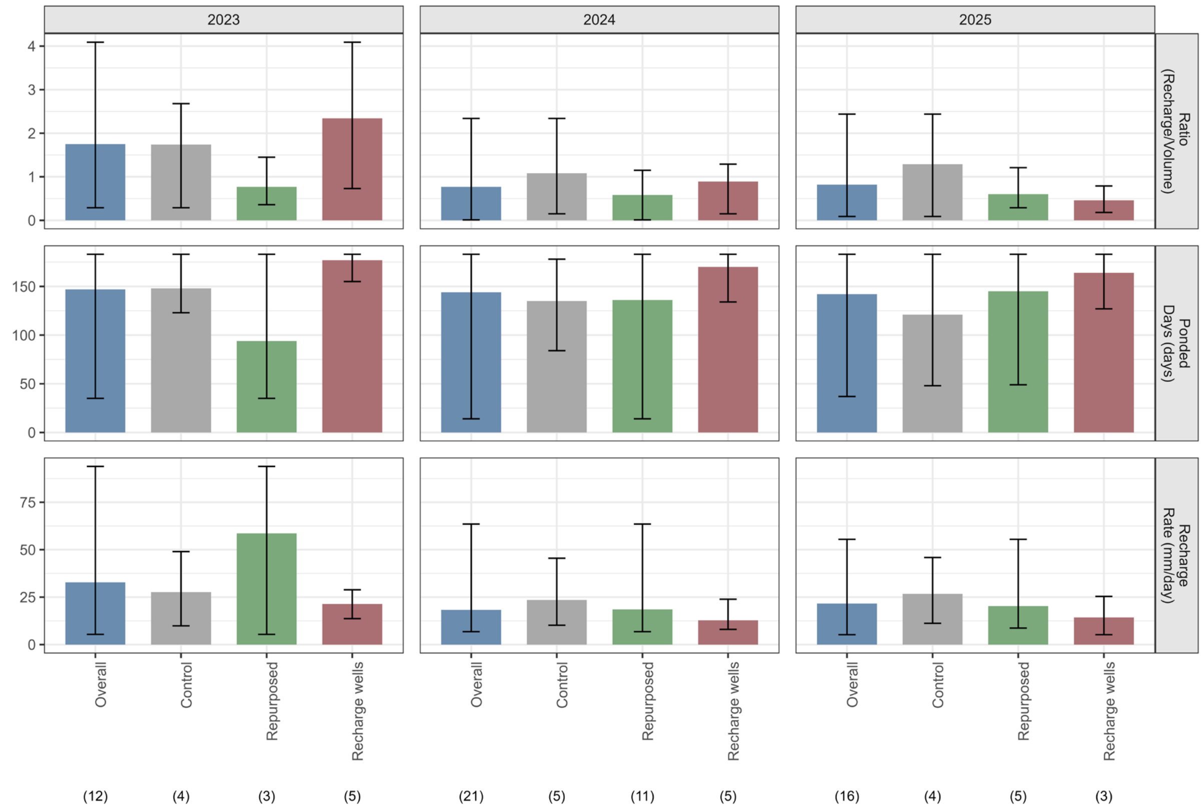


Figure 4. Mean Recharge volume (ration of recharge to pond volume), ponded days and recharge rates (mm/day) (bars show minimum and maximum) for overall and different type of ponds for the year 2023, 20424 and 2025. Note: Numbers at the bottoms shows number of sites monitored. Statistics derived from only those ponds which received water; Recharge period was taken 1st July to 31 Dec and for 2025, recharge estimated for Nov 25 and Dec 25 based average of last five values of last recharge event (*Source*: author's creation)

- ### Recharge rates

Despite generally good water availability, with ponds retaining water for more than 140 days on average, recharge rates (mm day^{-1}) emerged as the key limiting factor, resulting in modest overall recharge volumes. Across all site types and years, average recharge rates remained low with all average recharge rates (except one for repurposed ponds in 2023) being less than 40 mm day^{-1} ((Figure 3). Two clear patterns were evident. First, there were no significant differences in recharge rates among site types, with most values below 30 mm day^{-1}. Second, recharge rates consistently declined over time across all sites—most notably in recharge well and repurposed ponds. Average recharge rates dropped from 38.7 mm day^{-1} in 2023 to 20.0 mm day^{-1} in 2024 and 24.5 mm day^{-1} in 2025. For recharge wells, rates fell from 21.4 mm day^{-1} to 12.8 and 14.3 mm day^{-1}, while repurposed ponds declined from 56.2 mm day^{-1} to around 20 mm day^{-1} in later years. In contrast, control sites maintained relatively stable rates of approximately 25 mm day^{-1} throughout.

The combination of prolonged ponded periods and low recharge rates also led to significant evaporation losses. During the monitoring period, evaporation accounted for about 27–28% of pond storage capacity, underscoring the importance of enhancing infiltration efficiency to maximize recharge benefits.

The factors influencing recharge rates are discussed later but summary of key points from monitored data shows.

Key takeaways from monitoring results

- Recharge performance declined over time, with the recharge-to-storage ratio dropping from 1.75 in 2023 to about 0.8 in 2024–2025 across sites.
- Water availability was generally adequate (around 140 ponded days), with exception of a few poorly designed or sited ponds that remained dry or had minimal water.
- Recharge rates were consistently low and declining (15–59 mm day^{-1}), especially in recharge wells and repurposed ponds, limiting overall recharge volumes.
- High evaporation losses (about 27–28% of pond storage) further reduced recharge effectiveness, particularly in years with low infiltration rates.

Factors Influencing Recharge Rates

To understand what influenced recharge rates and why repurposed ponds did not perform better than control ponds, basic soil infiltration tests were conducted in 13 selected ponds in 2024 with design of sampling such that results were not sensitive to soil clogging layers. The measured infiltration (basic) rates[4] ranged from 11.5 to 96 mm day^{-1}, with an average of 43.5 mm day^{-1}. While some variation existed among sites, the average rates for control (40.9 mm day^{-1}), recharge well (47.6 mm day^{-1}), and repurposed ponds (42.7 mm day^{-1}) were broadly similar. This suggests that the lower recharge performance at repurposed sites is likely driven by factors other than soil infiltration capacity.

Maintenance and siltation of sites

Recharge rates showed a clear and consistent decline over the three years of monitoring, particularly in recharge well and repurposed ponds that had been rejuvenated earlier. This decline reflects the influence of local watershed conditions—mostly agricultural areas where high sediment loads from runoff accumulate within the ponds and gradually clog infiltration zones. In contrast, control ponds, which have not been recently desilted or rejuvenated, as expected showed relatively stable recharge rates over time.

Water quality tests showed pond-water turbidity ranging from 3–16 NTU. While such levels are generally acceptable for recharge, these measurements likely underestimate actual turbidity during runoff events. This is because samples were collected from the upper pond water layer and several days after rainfall, by which time most suspended silt would have settled. Field observations across nine sites confirmed significant sediment and clay mobilisation during monsoon runoff, with an average deposited silt layer of about 2 cm, though the thickness varied across ponds

Figure 5: Bottom of pond showing thick silt deposition (*photo*:IWMI)

All monitored sites were constructed or rejuvenated between 2020 and 2022, and the monitoring period covered one to five years after their last maintenance. As shown in Table 1, recharge rates declined steadily with years since rejuvenation—from

[4] steady, long-term speed at which water enters the soil after the initial, rapid infiltration slows down

“green” (higher rates) to “red” (lower rates)—except in a few cases where maintenance was carried out. For instance, at Daniya Sankarpur, cleaning of recharge wells in 2025 increased recharge from 23.9 to 25.4 mm day^{-1} and at Tewar Khas, full desilting more than tripled recharge rates from 15 to 55 mm day^{-1}. Without such interventions, these sites would likely have continued to show declining performance. For the monitoring period, in only 3 sites maintenance activity was observed.

Another key observation is the sharp reduction in recharge rates soon after construction as observed for the repurpose sites of Jargao and Sanai Roza. Sites built in 2022 showed a steep drop from the first to the second year (2023–2024), suggesting that even one year of siltation significantly reduced infiltration. This aligns with the high rainfall in 2023 (~1,400 mm), which likely accelerated sediment deposition and clogging of pond bottoms

Table 1. Construction year and recharge rate of repurposed and recharge well ponds across years

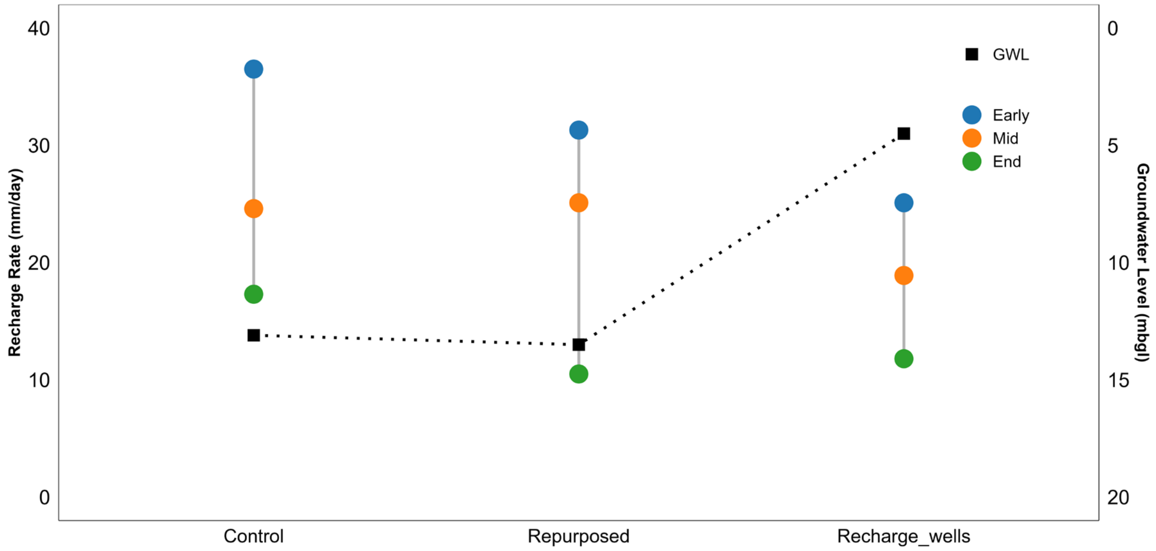
Site	Type	Construction year	Recharge rates (mm/day)		
			2023	2024	2025
Daniya Sankarpur[a]	Recharge wells	2020	28.9	23.9	25.4
Segankedra	Recharge wells	2020	13.7	13.4	12.3
Haryal	Recharge wells	2021	23.2	8.5	N/M[c]
Ramnagar Gangpur	Repurposed	2021	N/M	21.4	10.8
Signi	Recharge wells	2022	23.4	10.2	N/M
Tumdiya	Recharge wells	2022	18.0	8.0	5.2
Imratpur Seondara	Repurposed	2022	N/M	7.3	8.7
Jargao	Repurposed	2022	93.9	33.4	N/M
Mangoopura	Repurposed	2022	N/M	11.5	13.5
Sanai Roza (Amrit sarovoor)	Repurposed	2022	76.6	10.5	N/M
Sonakpur_Jogan	Repurposed	2022	N/M	8.5	12.8
Tewar Khas[b]	Repurposed	2022	N/M	15.1	55.5

[a] The filters in the recharge wells have been cleaned in year 2025
[b] Pond was desilted in 2025
[c] N/M – Not monitored: Site was not monitored.

Seasonal effects on recharge

Analysis of changes in recharge rates during the seasons shows a consistent decreasing trend as the season progresses, a pattern observed in all years (Figure 5). Recharge events occurring later in the season tend to be longer in duration, reflecting less frequent but prolonged rainfall of lower intensity. This suggests that early-season recharge events contribute more to total recharge, whereas later in the season, recharge is less and evaporation losses are higher. The decline in recharge rates during the monsoon season likely results from two key factors: (i) rising groundwater levels that reduce the hydraulic gradient, especially pronounced in areas where groundwater tables are shallow, and (ii) progressive siltation of recharge structures, which accumulates over time and becomes more evident across years (as noted earlier in Table 1). Similar trends were observed in the UTFI pilot in Rampur, where recharge rates declined later in the season as groundwater levels rose.

Although continuous groundwater level monitoring data was unavailable due to the absence of piezometers near most sites, data from nearby state and central monitoring wells were used to estimate groundwater levels wherever available. Pre-monsoon groundwater levels provide an indication of available storage at the start of the season. For control and repurposed sites, groundwater levels were generally deeper (> 10 mbgl), whereas for recharge-well sites—mostly located in Rampur—groundwater levels were shallower (< 5 mbgl). Evidence from the UTFI pilot suggests that groundwater level depths >5 mbgl do not constrain recharge. This suggests that recharge well sites face greater limitations from reduced hydraulic head and available storage as the season progresses. These conditions, coupled with limited maintenance, likely explain why limited recharge rates from recharge-well sites relative to control sites among all site types.



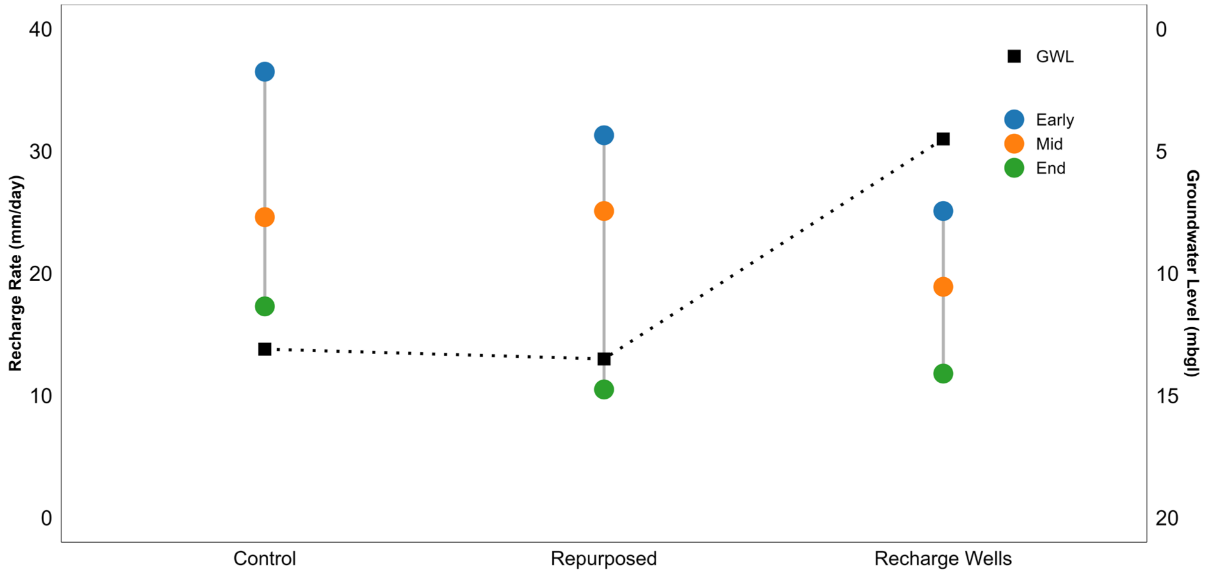


Figure 5. Mean recharge rate for different sites at different time of season: Early (June-July); Mid (Aug - Sep) and End (Oct-Dec) and the associated mean groundwater levels (GWL). (*Source*: author's creation)

Dead storage: activation of recharge wells

Another factor influencing the performance of recharge well sites is the designed dead storage. These sites were intentionally constructed so that the recharge well becomes active only after the pond water reaches a certain threshold level (typically 1–1.5 m above the pond bottom), thereby ensuring that minimum pond water levels remain available for other uses (e.g., livestock, recreational value). Consequently, during parts of the recharge season when water levels remained below this threshold, recharge through wells was absent.

When recharge events are disaggregated based on whether the average water level was above or below this threshold, a distinct seasonal pattern emerges. As shown in the figure 6, during the early part of the season, recharge rates are substantially higher when pond water exceeds the threshold (28.5 mm/day) compared to when it remains below (20.5 mm/day). However, this difference diminishes as the season progresses — during the mid-season, recharge rates are similar (19.7 vs. 18.4 mm/day), and by the end of the season, rates are nearly identical (12.2 vs. 11.4 mm/day).

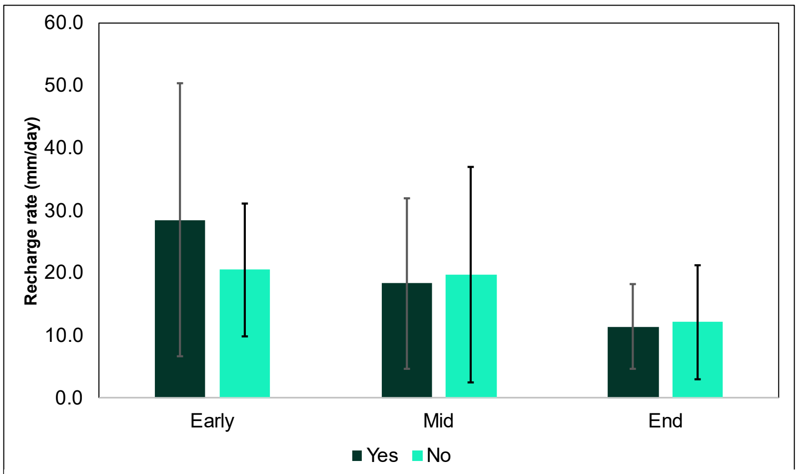


Figure 6. Mean recharge rate (and standard deviation) of recharge well sites below (No) and above (Yes) dead storage threshold (above threshold recharge wells are active) (*Source*: author's creation)

This pattern is consistent with expectations: early in the season, when groundwater levels are deeper, the higher hydraulic gradient supports greater recharge once the threshold is exceeded. Later in the season, as groundwater levels rise and available (desaturated) aquifer storage becomes limited specially in recharge well sites where groundwater levels are shallow, the effectiveness of recharge wells declines even when water levels in the pond remain high. This indicates that while recharge wells can enhance recharge under suitable conditions, their **effectiveness is highly site- and time-dependent**. In this case, **many recharge-well sites were not optimally located**, as shallow groundwater conditions later in the season limited their contribution to recharge.

Impact of recharge pits

To address the relatively low recharge rates observed at several repurposed sites, some were modified in 2025 by adding recharge pits. Recharge pits were preferred over recharge wells for two main reasons: (i) water entering recharge pits percolates through the vadose zone, allowing natural filtration before reaching the aquifer, unlike recharge wells that bypass this layer; and (ii) recharge pits are easier to construct, maintain, and clean. Four sites were modified with pits approximately 3 × 3 m in area and 2.5–3 m in depth terminating when the overlying low permeability layers were removed to reach more permeable sandy layers.

Monitoring results were mixed. Considering the general declining trend in recharge rates across years, even modest increases suggest positive intervention effects. For instance, at Jargao, recharge rates increased from 33.4 mm/day (2024) to 51.6 mm/day (2025), though still lower than the 2023 level (93.9 mm/day). At Chhiraoli, recharge improved from 12.0 mm/day to 18.4 mm/day, and at Changeri, from 6.8 mm/day to 10.4 mm/day. The Sonakpur site showed no notable change. While the absolute increases were modest, these results suggest that recharge pits helped halt the declining trend in recharge performance.

Overall, while the magnitude of improvement remains modest in absolute terms but important in relative terms, the results highlight the potential of recharge pits to stabilize or slightly enhance recharge rates, particularly where existing structures show siltation or declining performance. However, the observed increases from only 1–2 pits (covering < 1% of pond area) indicate that a larger number or area of pits would be required to produce significant recharge gains at the system scale.

Table 2. Recharge rate of repurposed ponds with recharge pits before (2023 and 2024) and after (2025) construction of recharge pits

Site	Recharge Pit Area (% of Pond)	Recharge rate (mm/day)		
		No recharge pit		With Recharge pit
		2023	2024	2025
Changeri	**0.06 %**	**5.4**	**6.8**	**10.4**
Chhiraoli	**0.23 %**	**N/M**	**12.0**	**18.4**
Jargao	**0.16 %**	**93.9**	**33.4**	**51.6**
Sonakpur Nari Kund	**0.26 %**	**N/M**	**13.6**	**13.6**

[c] N/M – Not monitored: Site was not monitored.

Estimated contribution to groundwater storage in the Ramganga basin

Using recharge rates and ponded-water days monitored over three years—along with pond-area data from about 1,300 ponds (3,000–6,000 m²) and the total number of ponds constructed/rejuvenated through MGNREGS in the Ramganga district—we estimated the total recharge contribution of MAR structures in the Ramganga basin. The calculation assumes that any pond could perform within the observed recharge range (Figure 3), experience an average of 140 ponding days, and follow the same area distribution as the 1,300 mapped ponds. Under these assumptions, the estimated mean recharge volume ranges from 12,852 to 22,908 m³ per pond per year.

Using this per-pond estimate and the total number of MAR structures in the region, we estimate that MAR development contributed approximately 152–271 MCM of recharge in the Ramganga basin in 2023. At the district level, MAR accounts for roughly 1.5–9.0% of total rainfall-recharge. To capture the basin's estimated 1,156 MCM of excess runoff needed to stabilize declining groundwater levels[5], about 50,000–90,000 MAR ponds would be required, based on current performance levels. To date, only about 12,000 structures—roughly 15–25% of the estimated need—have been developed. Although the waterbody census lists 35,414 ponds across these districts, many are unlikely to be suitable for MAR due to competing uses such as fisheries, agriculture (e.g., water-chestnut cultivation), or religious and recreational functions. Improving the recharge efficiency of existing MAR structures is therefore equally important. The average monitored recharge rate of ~25 mm/day is far below the 221 mm/day (164–295 mm/day) achieved at the UTFI pilot site in Rampur district over three years[6], indicating substantial potential for enhancing system performance.

Recommendations for Enhancing Pond-Based Recharge Performance

Reduce sediment inflow to sustain recharge performance: *To mitigate decline in recharge* performance due to sediment clogging, control silt at the source through catchment soil conservation and field/farm bunding and install silt traps with vegetative buffers at pond inlets to prevent heavy sediment entry to ponds during high-intensity rains.

Institutionalize regular maintenance and desilting: Mandate pond-bottom cleaning at least once every three years, funded through local budgets or MGNREGA (now VB-G RAM G). Evidence shows that recharge performance declines quickly due to high silt loads and infrequent desilting,

[5] Chinnasamy et al. (2017). Modeling the potential for floodwater recharge to offset groundwater depletion: a case study from the Ramganga basin, India. Sustainable Water Resources Management. https://doi.org/10.1007/s40899-017-0168-6
[6] Alam et al., (2020)

with most ponds showing substantial sediment buildup within three years. Current MGNREGA guidelines[7] prescribe a 5–10-year desilting interval, but this can be reduced for ponds—especially those designated for groundwater recharge.

Improve the effectiveness of recharge wells: 1) Site recharge wells only where groundwater levels are deeper than 10 mbgl to ensure adequate hydraulic head and depleted storage throughout the season; 2) include long term O&M plans that includes higher frequency mandatory filter cleaning and 3) lower dead-storage thresholds (currently 1–1.5 m) by earmarking selected ponds exclusively for recharge to enhance recharge rates throughout the monsoon season and reduce water-quality risks.

Promote low-cost recharge pits where ponds have multiple uses: Use recharge pits instead of wells in ponds that require dead storage or serve fisheries/agriculture. Pits provide natural filtration, are easy to maintain, and can significantly increase recharge rates, increase pit density beyond 1% of pond area.

Strengthen participatory management and performance monitoring: Engage local water champions, panchayats, or user groups to routinely track pond water levels and siltation using simple logbooks or mobile apps. Establish a standard monitoring framework with key indicators—such as recharge ratio, turbidity, and silt depth—to enable annual reporting and adaptive management. For schemes like Jal Sanchay–Jal Bhagidari (JSJB), link implementation incentives to measurable outcomes, including water availability, maintenance quality, and groundwater level improvements.

[7] https://nregaplus.nic.in/netnrega/writereaddata/Circulars/AMC_2024-25-English.pdf

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