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Research Article

The Silent Drawdown: Groundwater Depletion in the Ramganga Basin and Upper Ganga Doab, and a Framework for Sustainable Management

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Abstract

The plains of western Uttar Pradesh sit above one of the most intensively used aquifer systems in the world, and that aquifer is being drawn down. In situ observations indicate that the western part of the state and adjoining districts have lost tens of cubic kilometres of groundwater in under two decades, a decline corroborated by satellite gravity data and driven by a surge in deep tube wells, intensive irrigated cropping, reduced canal recharge, and drought-diminished rainfall. This paper synthesises the evidence for this silent drawdown in the Ramganga basin and the upper Ganga doab and proposes a framework for its sustainable management. It argues that the depletion is the outcome of a specific transition, from a canal-fed system that recharged the aquifer to a tube-well-fed system that mines it, and that management must therefore act on both sides of the water balance: reducing the demand that empties the aquifer and restoring the recharge that once refilled it. The framework combines demand-side measures, principally a shift away from the most water-intensive crops and a reform of the energy incentives that drive over-abstraction, with supply-side measures centred on reviving canal and surface-water recharge and developing managed aquifer recharge, and it binds these together through participatory groundwater governance. The framework is illustrated for the Ramganga basin and doab and is set within the water-energy-food nexus that the region so clearly embodies.

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1. INTRODUCTION

The groundwater crisis of the North Indian plains is largely invisible. Unlike a falling lake or a drying spring, a declining water table shows nothing at the surface until the well runs dry, and so the steady loss of the aquifer beneath western Uttar Pradesh has proceeded with little public alarm even as its scale has become extraordinary. In situ observations indicate that the western part of the state, together with adjoining districts, lost on the order of 62 cubic kilometres of groundwater between 2005 and 2023, a volume several times the capacity of India's largest reservoir, and satellite gravity measurements corroborate the decline (Mizan et al., 2026; Tiwari et al., 2009). This is the silent drawdown, and it is unfolding beneath one of the most populous and agriculturally vital regions on earth.

This paper synthesises the evidence for that drawdown in the Ramganga basin and the upper Ganga doab and proposes a framework for managing it sustainably. Its central argument is that the depletion is not simply the result of using too much water but the outcome of a specific hydrological transition. The region's aquifer was historically sustained in large part by recharge from a canal-irrigation system and from surface water, but the spread of the deep tube well has shifted the region to direct groundwater abstraction on a massive scale, so that a system which once partly refilled the aquifer now steadily empties it (Mizan et al., 2026; Rai et al., 2025). Understanding depletion as this canal-to-tube-well transition matters, because it implies that management cannot succeed by restraining demand alone; it must also restore the recharge that the transition removed.

The paper first sets out the evidence, drivers, and consequences of the drawdown, then develops a management framework acting on both demand and supply and bound together by participatory governance, and then illustrates it for the Ramganga basin and doab. The contribution is a synthesis and a framework rather than new measurement, and it situates the region's groundwater problem within the water-energy-food nexus whose interactions drive it (Hoff, 2011; Grey & Sadoff, 2007).

2. The drawdown: evidence, drivers, consequences

2.1 The evidence

The evidence for depletion in the region is now strong and convergent. Ground-based observations of the Upper Ganga Basin show a continuous, multi-decadal decline in groundwater levels and the loss of tens of cubic kilometres of storage in under two decades (Mizan et al., 2026). Satellite gravity measurements independently reveal the dwindling of groundwater across the northern Indian region and corroborate the rate of decline (Tiwari et al., 2009), and basin-scale analyses attribute the loss of Ganga-basin groundwater to a combination of natural and human drivers (Dangar & Mishra, 2021). Across the wider Indo-Gangetic basin, in situ mapping confirms both the scale of the resource and the reality of its depletion and quality problems (MacDonald et al., 2016). The convergence of ground observations, satellite data, and basin

modelling leaves little doubt that the drawdown is real, large, and sustained.

2.2 The drivers

The drivers form a connected system. The proximate cause is a surge in groundwater abstraction, as the number of deep tube wells has risen steeply and drawn increasingly on confined aquifers (Mizan et al., 2026). That abstraction is pulled by intensive irrigated agriculture, and pushed by an energy-pricing regime that makes pumping cheap, a policy-and-incentive structure widely identified as central to India's groundwater depletion (Chindarkar & Grafton, 2019). At the same time, the recharge side of the balance has weakened: reduced and more erratic rainfall, with summer-monsoon drying now accelerating depletion under climate change (Mishra et al., 2024), diminishes natural recharge, and the shift away from canal irrigation removes the substantial canal-fed recharge on which the aquifer once relied, a contribution that isotopic work has helped to quantify (Rai et al., 2025). Depletion is thus driven from both sides at once, by rising abstraction and falling recharge, and the two are linked through the same transition to tube-well dependence.

2.3 The consequences

The consequences reach beyond the aquifer. As shallow groundwater declines, users drill deeper, raising the cost of water, deepening inequality between those who can afford deep wells and those who cannot, and drawing on deeper waters whose quality may be poorer. Depletion threatens the very agriculture that drives it: falling groundwater is projected to reduce cropping intensity in India, undermining the food production the abstraction was meant to support (Jain et al., 2021). And because the region's grain enters national and international food systems, its groundwater loss is embedded in food produced and traded far beyond the doab (Dalin et al., 2017). The drawdown, in short, is not a contained hydrological curiosity but a threat to livelihoods, equity, and food security, which is why it demands management rather than mere observation.

3. Approach

The paper synthesises the converging evidence into a management framework rather than generating new data. Its organising idea is the water balance: depletion occurs when abstraction exceeds recharge, so sustainable management must close the gap from both directions, restraining the demand that empties the aquifer and restoring the recharge that refills it. This framing follows directly from understanding the drawdown as a canal-to-tube-well transition, since that transition both raised abstraction and cut recharge. The framework is developed on two further principles. The first is that groundwater is a common-pool resource used by millions of individual pumpers, so its management cannot be purely top-down but must engage users themselves, a recognition central to the literature on India's groundwater policy (Chindarkar & Grafton, 2019). The second is that the problem is a nexus

problem, in which water, the energy that pumps it, and the food it grows are inseparable, so that measures in one domain must account for their effects in the others (Hoff, 2011; Grey & Sadoff, 2007).

4. The canal-to-tube-well transition and the recharge deficit

The framework rests on reading the drawdown as the product of a transition. Under canal irrigation, a substantial share of the water applied returned to the aquifer as recharge, so the irrigation system, however inefficient, partly replenished the groundwater it drew upon; isotopic evidence confirms the importance of canal recharge to the groundwater of the Ganga plain (Rai et al., 2025). The spread of the deep tube well changed this relationship fundamentally. Tube-well irrigation draws directly from the aquifer and, being more controllable and reliable, has increasingly displaced canal supply, so that the recharge the canals provided has fallen even as abstraction has risen (Mizan et al., 2026). The result is a structural recharge deficit: the system has moved from one that refilled the aquifer to one that mines it. This reading is the analytical core of the framework, because it shows why demand restraint alone is insufficient. Even reduced abstraction, in a system that no longer recharges as it once did, may exceed the diminished recharge, so sustainable management must restore recharge as deliberately as it restrains demand.

5. A management framework

5.1 Demand-side measures

The first set of measures reduces the abstraction that empties the aquifer. The largest lever is agricultural: a shift away from the most water-intensive crops toward less thirsty ones would cut groundwater demand at its source, and because cropping choices are shaped by prices, procurement, and incentives, this is as much a policy question as an agronomic one. Behind cropping lies the energy incentive, since cheap or flat-rate power for pumping removes any cost signal against over-abstraction, and reform of that incentive is repeatedly identified as central to curbing depletion (Chindarkar & Grafton, 2019). Demand-side management thus reaches directly into the energy and food arms of the nexus, and its measures must be designed with their effects on farm livelihoods in view, since abrupt restraint imposed without alternatives would fall hardest on the vulnerable (Hoff, 2011).

5.2 Supply-side measures

The second set restores the recharge that the transition removed. The most direct measure is the deliberate revival of canal and surface-water recharge, recognising the canal network not only as a means of delivering irrigation but as an instrument of aquifer replenishment, a function the isotopic evidence shows was real and substantial (Rai et al., 2025). Beyond the canals, managed aquifer recharge, the intentional capture and infiltration of surface water and monsoon runoff to replenish the aquifer, offers a means of rebuilding storage where natural and canal recharge have fallen. Rejuvenating the surface-water bodies of the plains serves the same end. Supply-

side management treats recharge as something to be actively engineered rather than passively awaited, which is the necessary response to a structural recharge deficit.

5.3 Participatory groundwater governance

The third component binds the other two through governance. Because the aquifer is drawn upon by vast numbers of individual users, neither demand restraint nor recharge restoration can be imposed successfully from above alone; both require the understanding and participation of the users themselves. Participatory groundwater management, in which communities monitor their own aquifer and take part in decisions about its use, is the approach suited to a common-pool resource of this kind, and it is increasingly recognised in Indian groundwater policy as essential to any durable solution (Chindarkar & Grafton, 2019). Giving users knowledge of the state of their own aquifer, and a stake in its recovery, is what can convert the framework's technical measures into changed behaviour on the ground, and it connects this framework to the wider case for community-based water monitoring and governance.

6. Illustrative application: the Ramganga basin and upper doab

The framework can be read through the Ramganga basin and the upper Ganga doab, which exhibit the full pattern: intensive irrigated agriculture, a proliferation of tube wells, declining canal recharge, and a documented, sustained fall in the water table within the broader Upper Ganga Basin decline (Mizan et al., 2026; Rai et al., 2025). Applying the framework, demand-side action would target the region's most water-intensive cropping and the energy incentives that sustain heavy pumping; supply-side action would revive canal and surface-water recharge across the basin and develop managed aquifer recharge to rebuild storage; and participatory governance would engage the region's farmers in monitoring their aquifer and in the choices that determine its future. Because the region's crops feed distant markets, its recovery would also lighten the groundwater embedded in food consumed far beyond the doab (Dalin et al., 2017), and because its depletion is being accelerated by monsoon drying, its management is also a form of climate adaptation (Mishra et al., 2024). As throughout this paper, the application illustrates how the framework would operate rather than reporting new measurements, which implementation and monitoring would provide.

7. DISCUSSION

The framework's claim is that the silent drawdown of the western Uttar Pradesh plains is the product of a canal-to-tube-well transition that raised abstraction and cut recharge, and that sustainable management must therefore act on both sides of the water balance, bound together by participatory governance. Three implications follow. First, demand restraint alone is insufficient: in a system with a structural recharge deficit, restoring recharge is as essential as reducing abstraction, and

the deliberate revival of canal and managed recharge is central rather than supplementary (Rai et al., 2025; Mizan et al., 2026). Second, the problem is a nexus problem to its core, since the water is pumped by subsidised energy to grow food for distant markets, and effective measures must reach into the energy and food domains and weigh their effects on livelihoods (Chindarkar & Grafton, 2019; Dalin et al., 2017; Hoff, 2011). Third, governance must be participatory, because a resource abstracted by millions of individual users cannot be managed by decree alone (Chindarkar & Grafton, 2019). The framework is transferable to the other intensively pumped alluvial plains of India and South Asia, where the same transition and the same drivers recur (MacDonald et al., 2016). Its limitations are those of a synthesis: it integrates established evidence but does not itself quantify the recharge deficit for a specific basin, which would require dedicated water-balance study, and the political economy of reforming energy subsidies and cropping patterns is daunting. These define the agenda for the basin-scale analysis and the policy work that turning the framework into practice would require.

8. CONCLUSION

Beneath the fields of western Uttar Pradesh, one of the world's great aquifers is being drawn down in silence, its loss measured in tens of cubic kilometres and its cause rooted in a transition from a canal-fed system that recharged the groundwater to a tube-well-fed system that mines it. This paper has argued that managing the drawdown sustainably requires acting on both sides of the water balance, restraining the demand driven by intensive cropping and subsidised pumping while deliberately restoring the canal and managed recharge that the transition removed, and binding these through the participatory governance that a common-pool resource demands. Illustrated for the Ramganga basin and the upper doab and set within the water-energy-food nexus it so plainly embodies, the framework offers a way to arrest a depletion that threatens water, food, and livelihoods alike. Its promise rests on implementation, and on the willingness to treat recharge, energy, and cropping as the single system they are.

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