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Who gets water? Designing irrigation service under groundwater scarcity

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- **Relative position in an irrigation sequence shapes outcomes**: Farmers extracting later receive less water and earn lower returns because less water remains by the time their turn arrives, creating systematic welfare differences in sequential irrigation schemes.
- **Institutions reshape inequality through different channels:** Crop-based water quotas act as an ex-ante planning tool that limits over-extraction but does not prevent downstream shortfalls. Rotation and monitoring act as ex-post enforcement, improving fairness across irrigation cycles by rotating access, but later farmers still receive less water within each cycle.
- **Institutions shape resilience, not just allocation:** Different rules lead to different welfare paths--quota systems support faster recovery, while rotation and enforcement help stabilise losses over time.
- **Behaviour responds to incentives, not learning:** Farmers show little evidence of gradual learning or adaptation to past scarcity or peer behaviour. Instead, behaviour is persistent and reacts primarily to current constraints on water availability and institutional rules, with norm-sensitive (high-trust) farmers adjusting most strongly.
- **Policy should prioritise irrigation service delivery:** Improving irrigation outcomes requires better service design, considering how access is sequenced, scheduled, and guaranteed across farmers.

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The policy problem

Groundwater irrigation underpins agricultural production in many parts of the world, especially where rainfall is uncertain, and surface water systems are limited (Yang et al., 2024; Yao et al., 2025). In northern Bangladesh, Boro rice cultivation depends almost entirely on dry-season groundwater irrigation (Sadiq, Sarkar, & Raisa, 2023; Tulip et al., 2022). In these settings, irrigation is typically delivered through shared pumping systems, where multiple farmers rely on a common groundwater source accessed via a single pump or distribution network.

While this model has enabled large gains in rice productivity, it creates a fundamental allocation problem driven by congestion in groundwater use. As farmers draw water from a shared source, pumping by early users reduces the water available to those who follow (Pfeiffer & Lin, 2012; Smith, 2018). Because irrigation is delivered sequentially, position in the extraction sequence determines how much water is ultimately received.

This system generates systematic differences in water use; as groundwater levels decline and irrigation demand rises, particularly during peak periods in rice cultivation, these differences become more pronounced. In practice, this leads to recurring disputes over water access, perceptions of unfair distribution, and reduced trust in irrigation service providers. These patterns are not unique to Bangladesh.

Much of the existing research on irrigation and collective action has focused on small, self-governed systems, where farmers coordinate through communication, local rules, and social norms (e.g., Bernal-Escobar et al., 2025; Cardenas, Rodriguez, and Johnson, 2011; Janssen et al., 2012; Otto & Wechsung, 2014). While this work shows how cooperation can emerge, it pays less attention to how water is actually allocated in shared systems where access is sequential and physically constrained. As a result, we know relatively little about how differences in access affect economic outcomes, or how farmers cope with and recover from periods of severe water scarcity.

A key policy challenge is to design allocation systems that function fairly under these conditions. Addressing this problem is increasingly urgent. Climate change is expected to intensify water scarcity through declining rainfall and more frequent droughts, and irrigation demand continues to grow. Without effective institutional design, groundwater depletion may accelerate, and conflicts among users may become more frequent and harder to resolve.

This study addresses this gap by examining how a farmer’s position in the extraction sequence shapes access to water and economic outcomes under different allocation rules. It also analyses how farmers’ outcomes evolve when water shortages occur, and how different institutional arrangements influence the extent of losses and the speed of recovery.

What this research does

To better understand this problem, we conducted a field experiment with 60 rice farmers in northern Bangladesh. Farmers participated in a structured irrigation game designed to reflect how groundwater is used in shared systems. In each round, farmers first contributed to a shared irrigation fund that determined water availability and then extracted water in sequence, according to different allocation rules.

The study was implemented in groundwater-dependent irrigation schemes managed by service providers such as the Barind Multipurpose Development Authority and Solargao Limited. Farmers were organised into small groups representing a simplified command area, where several farmers share access to a common pumped water source and make decisions about both investment and water use.

The game was played over 30 rounds, allowing us to compare behaviour under three institutional settings: a baseline system with no restrictions, a planning rule with crop-based water limits, and an enforcement rule with rotational access and penalties for overextraction, with monitoring determined by random audit. Within each group, farmers were assigned positions in the extraction sequence, reflecting their relative access to the pump. Under the first two rules, this order remained fixed, while under the third rule, it rotated across rounds. This design allows us to isolate how a farmer's position in the sequence affects water access and outcomes, and how different institutional arrangements shape behaviour and responses to scarcity.

Key findings

Who gets water matters as much as how much water is available.

Farmers who receive water later in the sequence consistently face disadvantages. They extract less water and earn lower returns because less water is available by the time their turn arrives.

Institutional rules can reduce—but not eliminate—this disadvantage. Crop-based water quotas, introduced as an ex-ante planning mechanism, help control overall water use and reduce extreme over-extraction. However, downstream farmers still struggle to meet their minimum needs because these rules do not address how access is sequenced.

In contrast, rotation and monitoring operate as ex-post enforcement, improving fairness over time by reshuffling access and reducing persistent positional disadvantage. While these rules stabilise outcomes, they do not eliminate within-round scarcity.

A central contribution of the study is to show that institutional design shapes water allocation and resilience. When there is scarcity, welfare declines under all systems, but recovery patterns vary. Under the baseline system, losses tend to persist. Under quota-based systems, recovery is faster. Under rotation and enforcement, losses are more stable and less volatile.

Additional results highlight heterogeneity in farmer responses. Differences across farmers are driven primarily by water availability at the time of extraction rather than by behavioural differences. When water is abundant, positional disadvantage largely disappears. There is also little evidence of learning: behaviour changes mainly when rules change, not due to accumulated experience. While farmers tend to repeat past actions, they do not systematically adjust based on previous shortages or others' behaviour.

Finally, we observe that farmers with higher levels of trust respond more strongly to scarcity, reducing extraction more when they are in disadvantaged positions. However, these behavioural differences remain secondary to the dominant role of water availability and institutional design.

Policy recommendations

Reducing water conflicts in shared groundwater schemes requires shifting attention from how much water is used to how irrigation access is governed, including the rules that determine extraction order, allocation limits, and how water availability changes as extraction proceeds. In such systems, farmers may receive unequal amounts of water under the same allocation rules, because their position in the delivery sequence determines how much water remains available at the time of access. Addressing this requires policies that focus on the organisation of access. Several practical steps follow from this:

- **Introduce rotational irrigation schedules:** Rotating extraction order across irrigation cycles ensures that the same farmers are not consistently disadvantaged by their position in the system.
- **Guarantee a minimum level of irrigation service:** Each farmer should receive a basic level of water access, such as a minimum number of irrigation hours or a crop-adjusted allocation, before additional water is distributed. This helps protect tail-end users from exclusion.
- **Focus on service rules, not just pricing or penalties:** In many groundwater schemes, water is delivered as a service rather than traded in private markets, where a wealthy farmer sells water to fellow farmers from his or her own pump device. Clear and fair

allocation rules, such as irrigation schedules and quotas, are therefore needed to ensure equitable outcomes.

- **Use monitoring strategically, especially during scarcity:** Monitoring is most effective when water is scarce, because this is when the risk of exclusion and conflict is greatest. Targeted enforcement can discourage overuse without imposing unnecessary costs when water is abundant.

- **Improve transparency in water delivery:** Public schedules, simple record-keeping, and clear communication can reduce disputes and build trust by making allocation rules visible and predictable.

Implementation challenges

Groundwater management is not only about controlling extraction. Also critical is the design of irrigation schemes to deliver water more equitably. Implementing the aforementioned recommendations may face practical challenges. Rotational schedules can be difficult to enforce where farmers have established expectations about priority access or where preexisting power asymmetries challenge the implementation of rotational rules. Guaranteeing a minimum service level requires reliable monitoring of delivery, which may be constrained by limited infrastructure or operator capacity. Greater transparency may also expose perceived inequities, eroding trust. Finally, targeted enforcement during periods of scarcity depends on timely information about water availability, which may not be readily observable in groundwater systems.

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