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Climate-resilient and adaptive water management for resilient farming and improved productivity in Pakistan

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Abstract: This research addresses the challenges of climate-resilient and adaptive water management in Pakistan's Indus Basin Irrigation System (IBIS), focusing on both system-wide and field-scale interventions. At the provincial scale, the Water Apportionment Accord (WAA) Tool is being enhanced for more transparent, adaptive water allocation. Locally, participatory trials with water-wise technologies and socio-economic surveys are being conducted to improve irrigation decisions and explore flexible storage options. Pilot studies in tail-end farming communities demonstrate promising results for improving reliability, productivity, and resilience in irrigated agriculture.

Keywords: *Indus Basin, water allocation, climate resilience, adaptive management, irrigation, reliability, warabandi, smallholder farmers*

1. INTRODUCTION

The Indus Basin Irrigation System (IBIS) is vital for Pakistan's food and water security. Reliance on irrigated agriculture is increasing at the same time as population growth is driving up food demand, while climate change is projected to bring hotter conditions, more variable precipitation, and less reliable water supplies. Addressing this growing variability requires significant improvements in water allocation and use across multiple scales—provincial, canal command, and smallholder farms. It also requires more adaptive management of irrigation water delivery to reduce the vulnerability of smallholder farmers to fluctuations in water supply and demand. To address these challenges, with funding from the Australian Centre for International Agricultural Research (ACIAR 2024), a research project is being implemented to improve canal water reliability at (1) provincial and canal command scales through enhanced water allocation decision-making, and (2) the local scale by supporting farmers to 'do more with less' water.

The IBIS is an upstream-controlled, supply-driven system in which allocations are governed by the 1991 Inter-Provincial Water Apportionment Accord. This Accord defines volumetric shares for the 4 provinces of Pakistan – Punjab, Sindh, Khyber Pakhtunkhwa and Balochistan – and the Indus River System Authority (IRSA) regulates distribution accordingly. While the Accord sets out broad principles of water sharing, it does not specify the precise mechanisms for pre- and intra-season allocations, sharing of losses and gains between provinces, or rules for reservoir operations. Until recently, the pre-season allocation process was understood only by a small number of agency professionals, leading to differing interpretations and disputes, especially during periods of water scarcity. The Water Apportionment Accord (WAA) Tool (Ahmad et al. 2022) has been instrumental in making allocation rules explicit, exposing differences in interpretation, and providing an evidence-based platform for more transparent and equitable planning.

At the local scale, irrigation canals operate continuously, delivering water through ungated outlets to watercourses, where water distribution is managed by the century-old warabandi system—a traditional method of scheduling canal water in fixed turns among farmers, according to farm size. Farmers make cropping decisions according to anticipated water availability and their scheduled turns; however the rigidity of the system limits flexibility in adapting to seasonal and inter-seasonal variations in crop water demand, leaving tail-end farmers especially vulnerable. At each water turn, farmers must decide whether to irrigate particular crops or fields, or wait for the next turn. This often results in under- or over-irrigation, impacting crop productivity. Additionally, at the local scale, the absence of intermediate and on-farm storages further exacerbates variability within the IBIS, as farmers are unable to buffer excess flows during wet periods or store water for dry spells. These constraints undermine reliability—a key ingredient for building resilience in farming communities.

To address provincial and canal command scale challenges, the WAA Tool is being enhanced. Current developments include improving its spatial resolution down to the canal command level and incorporating intra-season planning capabilities that account for flow lag times, gain/loss assessments, actual reservoir

volumes, and forecasted inflows. Stakeholders are actively engaged in the development; and to ensure that the Tool meets their water planning needs, development is being carried out in two phases: a proof-of-concept implementation for testing, followed by a final product designed for operational decision-making.

To address field-scale water management challenges, a suite of water-wise technologies such as Chameleon soil moisture sensors, wetting front detectors, and nutrient testing kits are being deployed on farmer fields. These tools provide outputs as colours to guide irrigation decisions on when and how much water needs to be applied (Stirzaker and Driver 2024). These participatory trials will expose farmers to the availability and effectiveness of these tools, helping them evaluate their potential for efficient decision-making.

To address the rigidity of the supply system for local-scale uses, socio-economic surveys and focus group discussions are being conducted to understand the potential of localised storage options as a means to introduce flexibility into the system, aiding the transition from a strictly supply-based system to a more demand-driven approach. This participatory research approach will generate evidence on adoption potential, livelihood impacts, and opportunities to strengthen resilience and equity in water use among smallholder farmers.

2. PROGRESS TO DATE

For the system scale component, enhancements for pre-season planning have already been implemented, and the software has been released for stakeholder testing. Extending the Tool's resolution to canal headworks will enable provinces and agencies to make more adaptive and transparent allocation decisions. Once intra-season planning functionality is fully integrated, the Tool will improve water delivery reliability and reduce fluctuations in canal supplies—both key prerequisites for sustaining irrigated agriculture.

For the local scale component, a pilot site has been established at Chak GB307, located at the tail of the Lower Gugera Branch in the Lower Chenab Canal system. A baseline bio-physical and socio-economic survey from 85 farming families is completed which has helped understand the key land uses as well as issues and opportunities for irrigated farming. Field scale strategies to 'do more with less' are being tested in partnership with local farming communities and research institutions. In the initial phase, VIA tool has been deployed at five cotton-wheat field in the head, middle and tail reaches on watercourse commands in the selected village. Initial field trials on cotton-wheat cropping system showed promising results. This work is being extended to an additional 13 fields representing other key land uses of cotton-raya, citrus orchards, and /kitchen gardening.

3. CONCLUSIONS

The integration of innovative water-wise technologies and adaptive planning tools is set to significantly enhance the reliability and efficiency of water allocation across multiple scales. By fostering ongoing collaboration among stakeholders, the project strengthens both the resilience and sustainability of irrigated agriculture within the IBIS system. Evidence generated from participatory research and field trials will inform future strategies, promoting equitable water use and improved livelihoods for smallholder farmers. Ultimately, these efforts pave the way for a more flexible and demand-driven approach to water management in the region.

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