From Snowmelt to Fields: Synthesizing Water Supply, Use, and Management Gaps across Kabul River Basin

Fazlullah Akhter[a], Usman Khalid Awan[a], Christian Borgemeister[a], Bernhard Tischbein[a]

[a]*Center for Development Research (ZEF), University of Bonn, Germany*
Email: fakhtar@uni-bonn.de

Abstract: The Kabul River Basin (KRB) faces classical water management challenges arising from high interannual climate variability, deteriorating irrigation infrastructure, inefficient allocation, and unsustainable groundwater use. Decades of underinvestment in hydrological monitoring, conveyance, and drainage systems have left the basin unable to respond effectively to increasing agricultural and urban water demands. These challenges manifest as mismatches between water supply and demand across scales: from seasonal and interannual fluctuations in upstream inflows, to mid-basin conveyance losses, to on-farm inefficiencies in irrigation timing. Addressing them requires a basin-wide perspective that links upstream water generation, mid-basin distribution, and field-level application, while identifying leverage points for targeted policy reform and infrastructure development.

This study synthesizes four complementary hydrological analyses to provide an integrated view of water supply, use, and efficiency in the Kabul River Basin. Water supply from the snow-fed upper basin was quantified using a calibrated SWAT rainfall–runoff model (Akhtar et al., 2022a). Basin-wide actual evapotranspiration (ET_a) was mapped using the SEBS algorithm applied to MODIS and GLDAS data (2003–2013) and validated against the Advection–Aridity method (Akhtar et al., 2018). Groundwater storage trends were assessed using GRACE satellite total water storage anomalies combined with GLDAS soil moisture to estimate groundwater storage anomalies (Akhtar et al., 2022b). Farm-level irrigation scheduling for winter wheat was evaluated using the FAO AquaCrop model under current farmer practice and optimized scheduling scenarios (Jalil et al., 2020).

The SWAT model estimated mean annual runoff of 1.94 km³/year for the Alingar watershed (≈10% of the Kabul River Basin flow), with March–June peaks and projected 15–16% declines by 2045 under Representative Concentration Pathways (RCP) 4.5 and 8.5 (Akhtar et al., 2022a). SEBS-based ET mapping showed a ~9% increase in annual ET_a over 2003–2013 due to cropland expansion and intensified cropping, but relative ET (RET) frequently fell below 0.65 in tail-end irrigated areas, indicating inequitable distribution (Akhtar et al., 2018). GRACE analysis revealed strong seasonal recharge–depletion cycles but a long-term groundwater storage decline of −301 ± 527 mm/year, equivalent to a cumulative net depletion of ~4.82 m over 2002–2017 in the Kabul River Basin (Akhtar et al., 2022b). AquaCrop modelling demonstrated that optimized deficit irrigation schedules could increase water productivity by 78–95% while maintaining or slightly improving yields, particularly in middle and lower basin zones. AquaCrop modelling demonstrated that optimized irrigation schedules could reduce applied water by 25–35% without yield loss, especially in middle and lower basin zones (Jalil et al., 2020).

Inefficiencies and risks in the Kabul River Basin are interconnected across scales: reduced upstream flows limit allocations, conveyance losses and inequitable distribution deepen tail-end shortages, and poor irrigation scheduling heightens on-farm stress, driving unsustainable groundwater use. Groundwater dependence is therefore a symptom of systemic allocation and delivery weaknesses. Tackling these challenges demands coordinated investment in canal and drainage rehabilitation, groundwater recharge, snowpack-informed allocation, and improved on-farm scheduling. This synthesis links headwater generation to field application, providing a clear basis for policy and infrastructure actions to enhance water productivity, equity, and long-term resilience.

Keywords: *Integrated water management; Evapotranspiration; Groundwater depletion; Irrigation efficiency environmental data analysis*

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