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Signatures of human intervention – or not? Downstream intensification of hydrological drought along a large Central Asian River: the individual roles of climate variability and land use change

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The transboundary Helmand River basin is the main drainage system for large parts of Afghanistan and the Sistan region of Iran. Due to the reliance of this arid region on water from the Helmand River, a better understanding of hydrological drought pattern and the underlying drivers in the region are critically required for an effective management of the available water. The objective of this paper is therefore to analyse and quantify spatio-temporal pattern of drought and the underlying processes in the study region. More specifically we test for the Helmand River Basin the following hypotheses for the 1970-2006 period: (1) drought characteristics, including frequency and severity systematically changed over the study period, (2) the spatial pattern and processes of drought propagation through the Helmand River Basin also changed and (3) the relative roles of climate variability and human influence on changes in hydrological droughts can be quantified. It was found that drought characteristics varied throughout the study period, but did largely show no systematic trends. The same was observed for the time series of drought indices SPI and SPEI, which exhibited considerable spatial coherence and synchronicity throughout the basin indicating that, overall, droughts similarly affect the entire HRB with little regional or local differences. In contrast, analysis of SDI exhibited significant negative trends in the lower parts of the basin, indicating an intensification of hydrological droughts. It could be shown that with a mean annual precipitation of ~250 mm y^{-1}, streamflow deficits and thus hydrological drought throughout the HRB are largely controlled by precipitation deficits, whose annual anomalies on average account for ±50 mm y^{-1} or ~20% of the water balance of the HRB, while anomalies of total evaporative fluxes on average only account for ±20mm y^{-1}. The two reservoirs in the HRB only played a minor role for the downstream propagation of streamflow deficits. Irrigation water abstraction had a similarly limited effect on the magnitude of streamflow deficits, accounting for ~10% of the water balance of the HRB. However, the downstream parts of the HRB moderated the further propagation of streamflow deficits and associated droughts in the early decades of the study period. This drought moderation function of the lower basin was gradually and systematically inverted by the end of the study period, when the lower basin eventually amplified the downstream propagation of flow deficits and droughts. This shift from drought moderation to drought amplification in the lower basin is likely a consequence of increased agricultural activity and the associated increases in irrigation water demand from ~13 mm y^{-1} at the beginning of the

study period to ~23 mm y^{-1} at the end and thus in spite of being only a minor fraction of the water balance. Overall the results of this study illustrate that flow deficits and the associated droughts in the HRB clearly reflect the dynamic interplay between temporally varying regional differences in hydro-meteorological variables together with subtle and temporally varying effects linked to direct human intervention.