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Coupling physically-based and data-driven models for assessing freshwater inflow into the Small Aral Sea

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The Aral Sea and its basin are among the highly recognizable examples of significant environmental changes which took place in the Central Asia during the last decades. Induced by river runoff exploitation across huge irrigation systems the Aral Sea level has significantly decreased and run irreversible ecosystem and water balance shifts. Nowadays the Small Aral Sea has no straightforward hydrological connection with dying southern sea basins and tends to stay a separate part under current social and political situation in the region. It is extremely important to devote scientific attention to this region as a real live example of the human-induced impact on water balance and its response.

The main volume of the freshwater inflow into the Small Aral Sea is formed on the Syr-Darya river basin which is among the largest and highly-vulnerable river basins in the Central Asia. There are thirteen large reservoirs and much local water management related installations on the Syr-Darya river and its tributaries which utilize full freshwater potential for irrigational, industrial, recreational, and social needs. This complex structure of water management system coupled with the total absence of data describes its functioning is a challenge for any approach directed to the accurate assessment of the Small Aral Sea freshwater budget formation and evolution across the basin.

Taking into account these obvious challenges we have built a hydrological modeling system based on coupling ensembles of physically-based runoff formation models and a cascade of data-driven statistical models. Physically-based models (HBV, GR4J, SIMHYD) were calibrated for assessing daily runoff for twenty-four mountainous river basins, then parameters regionalization procedure based on spatial proximity were used for deriving gridded runoff dataset for the delineated Syr-Darya river runoff formation zone. Data-driven models (Random Forest, Gradient Boosting) were trained successively for four river runoff gauges on the Syr-Darya river based on all available monthly observations using leave-one-out cross-validation technique for avoiding overfitting.

The provided gridded dataset for monthly runoff assessment for basins in the formation zone is in good accordance with the observational data (median coefficient of determination is 0.6). Results also show a good efficiency of data-driven model ensembles to reproduce monthly river runoff alongside the Syr-Darya river: coefficient of determination between observed and ensemble mean values varies from 0.6 to 0.8. Sensitivity analysis of data-driven models' inputs reveals the dominant importance of runoff realization derived from the formation zone gridded runoff dataset which is based on a physical realism of used lumped hydrological models. Based on the stationarity assumption of runoff formation and water use processes we have simulated a scenario of freshwater inflow into the Small Aral Sea for a modern period. Results show a clear pattern for sea recovery under post-Soviet Union conditions. Our work shows the possibility to develop a valuable water assessment tool both for territories with complex water management system and strong water-related data scarcity.