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A process-based analytical derivation approach for estimating nonstationary annual runoff distribution

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A process-based analytical derivation approach is proposed to perform a nonstationary analysis for annual runoff distribution by taking into account the information of nonstationarities in both hydrological inputs and runoff generation processes. Under the Budyko hypothesis, annual runoff is simulated as a formulation of hydrological inputs (annual precipitation and potential evaporation) by using the Fu equation with a parameter w to account for the runoff generation processes. For reflecting the nonstationarity of the runoff generation process, the annual runoff model based on the Fu equation with a dynamic parameter w is constructed. Then the multivariate joint probability distribution among the hydrological inputs, the Fu-equation parameter w, and the runoff model error k is constructed via Pair copula on the basis of the nonstationary marginal distributions of both the hydrological inputs and w. Finally, the annual runoff distribution is derived by integrating the multivariate joint probability density function. The Hanjiang and Ganjiang watersheds in the Yangtze basin as well as the Weihe and Fenhe watersheds in the Yellow basin are chosen as the study regions. The derived distributions by the process-based analytical derivation approach perform well in fitting annual runoff distributions of all study watersheds. The results also indicate that both of the hydrological inputs (mainly potential evaporation) and the Fu equation parameter w of the Hanjiang, Weihe and Fenhe watersheds are found to be nonstationary. For the Ganjiang watershed, only the hydrological input of potential evaporation is nonstationary, while the Fu equation parameter w is a constant. Therefore, the derived runoff distributions for all study watersheds are nonstationary.