ABSTRACT

Streamflow droughts are recurrent hydrological hazards that increasingly threaten water-food and energy nexus, triggering socioeconomic crises. Existing global drought datasets are generally limited to monthly meteorological or grid-based hydrological indicators, whereas global-scale streamflow drought characteristics based on observed discharge at finer temporal resolutions remain lacking. Despite advances in multivariate analyses of streamflow droughts, the physical (climate: in isolation and dry-hot climate stressors in drought preconditioning; catchment, vegetation and soil) and statistical controls (explaining the spatiotemporal dynamics, onset seasonality-deficit volume interdependence, and persistence) are not well explored. Notably, the timing of drought onset and its linkage with deficit volume remain underexplored, despite their central role in hazard assessment, monitoring, and impact evaluation. This study at first introduces the Global Streamflow Drought Database v1 (GSDD-v1), a comprehensive inventory of streamflow drought events, including onset and termination times, and accumulated deficit volume across 2,998 regulated and unregulated catchments in 29 IPCC climate regions for 1950–2024, enabling robust basin-scale drought risk assessment. The daily variable threshold approach is used to identify streamflow droughts, demonstrating its effectiveness in capturing drought occurrences, particularly in river basins with highly seasonal flows resulting from monsoonal circulation and snowmelt processes. Results show that a significant rising trend in streamflow droughts at a global scale at a rate of slightly over 10 events/decade from 1901–2023, with an average count of ~35 events/year during 1901–1930 to an average count of 140 events/year during 1990–2020. This increase in long-term trend in streamflow drought frequency is accompanied by a substantial shift in distributions of onset time and deficit volume in the recent climate normal period (1991–2020) across global tropics compared to the past (1961–1990). A notable shift towards higher values in deficit volume with an increase in drought frequency is observed over the Northeast and South American Monsoon regions, Western Africa, Eastern South Africa, and north and eastern Australia, respectively. In the recent times, approximately one-third of sites portray a rising trend in deficit volume accompanied by a delayed onset of droughts. Meanwhile, the total versus upper tail dependence strengths between onset time and deficit volume show a prominent increase in total dependence strength in the recent time window for nearly 50% of catchments, indicating that severe droughts tend to occur more regularly and are closely linked with seasonal drought onset. However, the upper tail dependence strengthens in Eastern and Western Southern Africa, North-Central America, and Eastern North America, highlighting that severe seasonal droughts tend to dominate in these regions. Among physical controls of streamflow droughts, soil organic carbon and stock emerge as dominant drivers controlling the streamflow drought onset time in Peninsular India. Likewise, sand content and vertical distance to channel network typically control the streamflow drought deficit volume. Globally, climate significantly influence both compound and uncompounded streamflow droughts. Hotspots of compound droughts are spatially clustered in arid regions of northwestern North America and central Europe in the Northern Hemisphere, whereas in eastern South America and northeastern Australia in the Southern Hemisphere. On the impact side, accounting for onset seasonality, more than half of catchments (~56%) show at least a two-fold increase in the drought hazard when compounded by precipitation deficits and elevated potential evapotranspiration within ±2 months of drought onset, relative to uncompounded streamflow droughts. The nonstationary changes identified in individual drought attributes and their joint dependence as a function of onset seasonality can reshape the hazard potential of extreme droughts, with direct implications for risk management, water resources planning, climate adaptation, and drought forecasting. Finally, linkages between inferred dominant low-flow generation mechanisms and specific combinations of environmental controls are synthesized to aid in developing modelling tools for low-flow simulations and predictions. The study advances the multi-hazard investigation of streamflow droughts and the derived insights can aid more robust planning and decision-making.

Keywords: Streamflow droughts, Onset seasonality, Deficit Volume, Linear-circular dependency, Upper tail dependency, Compound drought, Drought hazard.