



OPEN Design storm estimation for flood risk assessment in the temperate Himalayan basin using hydrological modelling

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Flood frequency analysis and hydrological modelling are crucial for water resource management and flood mitigation, especially in regions vulnerable to extreme weather. This study utilises the HEC-HMS hydrological model to simulate rainfall-runoff processes and generate design storms for various return periods across 24 sub-watersheds of the Jhelum Basin, Kashmir. The model setup includes rainfall transformation using the ModClark method, baseflow estimation through the Linear Reservoir Method, and flood routing via the Muskingum approach. Satellite-based gridded rainfall data and sub-basin-specific hyetographs were used as meteorological inputs to ensure spatially distributed precipitation representation. Calibration and validation were performed using discharge data from Sangam, Ram Munshibagh, and Asham gauging stations (2020–2023), covering five high-flow events. This research marks the first application of event-based design storms at the sub-watershed scale in the Kashmir Valley using HEC-HMS, providing high-resolution insights into flood risk patterns. The model showed strong agreement with observed hydrographs ($R^2 > 0.78$, $NSE > 0.56$, $RSR < 0.6$, $PBIAS$ within $\pm 25\%$). Sensitivity analysis identified curve number, time of concentration, and infiltration rates as key parameters influencing performance. Results indicated varied hydrological responses, with watersheds like Lower Jhelum, Sindh, Lidder, and Pohru showing higher peak discharges due to steep slopes, while low-lying areas such as Wular-II and Anchar exhibited prolonged flood retention. Urbanised watersheds like Dal and Wular-I showed moderate to high peaks, highlighting infrastructure vulnerability. Design storms for 2–500-year return periods identified critical flood-prone zones, offering insights for infrastructure planning and risk management. This research highlights the effectiveness of HEC-HMS model as an important non-structural flood mitigation measure in a mountainous region of Kashmir.

Keywords Design storm, Flood, HEC-HMS, Hydrological modelling, Jhelum basin

Hydrological modelling is an important tool in water resource planning, flood hazard mapping and infrastructure design^{1–3}. It simulated the hydrological processes such as precipitation, infiltration, surface runoff, and channel flow to predict how the water will flow in a watershed^{4–6}. Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) is the most commonly used model among the commonly used hydrological models to analyse flood risks under different hydrological conditions^{7–9}. The integration of these models with remote sensing (RS) and geographic information system (GIS) technologies has significantly increased the accuracy of these models¹⁰.

Event-based rainfall-runoff models simulate the hydrologic responses of individual peak storm events, which makes them ideal for flood forecasting and infrastructure design^{11,12}. These models differ from continuous models in the aspect that they focus on individual storms, hence eliminating the computational needs but capturing peak discharges, which are needed for infrastructure design⁸. The models prove useful in

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