



## A Copula Framework for the Development of an Integrated Heat Index and Joint Return Period Analysis

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Heatwaves pose significant risks to human health, agriculture, and environmental systems and thus have received substantial attention globally. However, the lack of a standardized definition, with thresholds varying in terms of duration, magnitude, and contributing variables, often complicates the evaluation of heatwave risks. Addressing this gap, this study proposes a copula-based framework for developing an Integrated Heat Index (IHI) that synergistically incorporates daily maximum temperature ( $T_{\max}$ ) and daily minimum relative humidity ( $RH_{\min}$ ) to analyze heatwave variability across India. This study utilizes high-resolution ( $0.5^\circ \times 0.625^\circ$ ) data obtained from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), covering a period of 43 years (1981–2023) and focusing on the pre-monsoon (March–May) and monsoon (June–September) seasons. We used the Kolmogorov–Smirnov test to find the best marginal distributions for  $T_{\max}$  and  $RH_{\min}$ . Eight different distributions were examined: Extreme Value, Generalized Extreme Value, Generalized Pareto, Logistic, Normal, Gamma, Lognormal, and Weibull. We used copula functions (Gumbel, Clayton, Frank, and Gaussian) to model joint dependencies and chose the best copula based on Akaike Information Criterion (AIC). In this study, a heatwave is characterized by its attributes, such as frequency ( $F$ ), accumulated intensity ( $I_{\text{cum}}$ ), peak intensity ( $I_{\text{peak}}$ ), and duration ( $D$ ). Although these characteristics of heatwaves are closely interconnected, they are often studied separately, especially over the Indian subcontinent. Here, we assess the joint return period of heatwaves over India using bivariate analysis, considering the combinations of  $D$ - $I_{\text{peak}}$ ,  $D$ - $I_{\text{cum}}$  and  $I_{\text{peak}}$ - $I_{\text{cum}}$ . This integrated approach offers a robust tool for assessing heatwave dynamics and provides critical insights into their spatial and temporal variability across India, facilitating improved risk assessment and management strategies for diverse stakeholders.