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A first step towards the derivation of non-stationary design rainfalls for Australia

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Abstract: The magnitude and frequency of extreme rainfall events are likely to increase in a warmer climate escalating future flood risk. Therefore, infrastructure designed on the basis of historical data are less likely to able to withstand future changes in flood risk. Engineering infrastructure such as urban sewerage systems, urban drainage systems, levees, and bridges are designed using rainfall from Intensity-Frequency-Duration (IFD) curves. The IFD curves are constructed from historic annual maximum rainfall records across different storm durations and exceedance probabilities. As a first step towards understanding how IFD curves will differ in a warmer future we need to assess changes in the rainfall used in their derivation. Where past studies have examined the changes in extreme rainfall across Australia, they have had disparate results. Moreover, these results are not comprehensively conducted across the spatial extent of the Australian continent or the temporal range used in IFD construction. Therefore, further work is needed to better understand extreme rainfall changes across different storm durations and exceedance probabilities under a warming climate.

Our study investigates changes in extreme rainfall (annual maximum to 1% AEP) due to climate change across a range of storm durations and exceedance probabilities across Australia. Annual maximum rainfalls were extracted for 6, 12, 18, 24, 30 min, 1, 2, 3, 6, 8, 12 hr, and 1, 2, 3, 5 ,7 day durations from observed sub-daily records at 42 sites over the common period of 1967-2021. The presence of monotonic trend in each annual maxima series for each storm duration was evaluated using a Mann-Kendall test at a 5% significance level with the magnitude of the trend derived from Theil-Sen slope estimator. Non-stationarity was then assessed by fitting a Generalized Extreme Value Distribution (GEV) under four different assumptions: 1) stationary, 2) non-stationary location parameter, 3) non-stationary scale parameter, and 4) non-stationary location and scale parameters with time as a covariate.

We find that over the last 55 years shorter duration (6, 12, 18, 24, and 30 min) annual maximum rainfalls have increased across Australia, but longer duration annual maxima (>1 hr and 1 day) show fewer trends with some sites exhibiting negative trends with time. The development of different non-stationary GEV models for annual maxima rainfall across the 16 different durations and annual exceedance probabilities (AEP) ranging from 1 in 2 AEP to 1 in 100 AEP indicates that we need to be cautious with the model selection. Based on Akaike Information Criteria (AIC) metric, two different non-stationary GEV models (one with non-stationary location and scale parameters, the other with non-stationary location parameter), were found to be superior at a majority of sites for short duration rainfall and at a minority of sites for longer durations. However, when changes in quantile estimates over the 1967-2021 period were examined it was found quantile estimates derived using the non-stationary location GEV model did not change with exceedance probability. Based on past studies and our physical understanding of extreme rainfall changes increases are greater for short duration than those for longer duration, and rainfall increases are greater for rare events (1 in 100 AEP) than those for frequent events (1 in 2 AEP), and only the model based on non-stationary location and scale parameters in the GEV model was able to provide estimates that are consistent with our physical understanding of changes in extreme rainfall. We hence conclude that trends in annual maxima are best represented by non-stationary models that incorporate changes in both location and scale parameters.

Keywords: *Extreme rainfalls, climate change, extreme value distribution*