Extreme Value Analysis on the Vulnerability of Detroit from Heavy Rainfall

Rainstorms can lead to significant economic and societal disruptions, including flooding, infrastructure damage, and soil erosion. As such, monitoring daily precipitation levels, particularly extreme values, and predicting the likelihood of heavy rainfall in the future is crucial. We collected daily precipitation data from January 1st, 1959, to December 31st, 2022, observed at Detroit Metro Airport, Michigan, US. Subsequently, we employed the generalized extreme value (GEV) and generalized Pareto distribution (GPD) models to fit this data, assessing their goodness-of-fit using QQ-plots. Finally, we calculated the return levels for various year intervals, examined precipitation trends in Detroit, and derived insights for potential preventative measures.

The collected data is recorded on a daily basis. To analyze it, we grouped the data annually and determined the highest precipitation value for each year. From our data summary, only two years—1998 and 2014—experienced a maximum daily precipitation exceeding 100mm, registering at 110.2mm and 116.1mm, respectively. Notably, in the 64 years of observation, 35 years (which is more than half) saw their highest daily precipitation fall between 50mm and 100mm. To apply the GEV model, we employed the maximum likelihood estimation to derive the three parameters (location, scale, shape) characterizing the GEV distribution. The QQ-plot, comparing the order statistics of our data to the GEV quantiles, closely resembles a straight line as depicted in Figure 1 (left), indicating a satisfactory fit of the distribution to our data.

To forecast future extreme precipitation events, we determined return levels using the GEV model. An m-observation return level signifies a threshold anticipated to be surpassed once every m years. The computed return levels were 77.34mm, 128.67mm, 180.13mm, and 207.68mm for return periods of 10, 100, 500, and 1,000 years, respectively. Since a daily precipitation exceeding 200mm is considered exceptionally extreme, the likelihood of Detroit experiencing such a severe rainfall event remains relatively low.

Subsequently, we employed the Generalized Pareto Distribution (GPD) as an alternative model to fit the data. Prior to this, we utilized the empirical Bayes method to estimate the shape and scale parameters of the GPD. The derived shape parameter was 0.156, and the scale parameter amounted to 7.807. The QQ-plot, comparing the order statistics of our data with the GPD quantiles (as shown in Figure 1, right), suggests an even better fit than the GEV model. Leveraging a method akin to that used for the GEV, we calculated the return levels to be 86.89mm, 143.95mm, 197.94mm, and 225.71mm for the return periods of 10, 100, 500, and 1,000 years respectively. Notably, these values are consistently higher than those derived from the GEV model.

Both models we developed carry significant implications for understanding and mitigating the impact of extreme rainfall events in Detroit. Specifically, daily rainfall levels ranging from 100mm to 180mm are associated with risks of landslides and flooding. Accordingly, proactive measures, such as infrastructure maintenance, should be undertaken at least once every decade. This recommendation stems from the fact that the 10-observation return levels in both models hover near the 100mm mark, suggesting an estimated likelihood of daily maximum precipitation surpassing 100mm once every ten years. Moreover, by examining a line chart plotting the maximum daily precipitation against the year, it becomes evident that there is no discernible trend, either increasing or decreasing, in the temporal dependence of annual maximum rainfall.

In summary, the GPD model appears to be a more suitable choice over the GEV for our dataset, though both models suggest that Detroit is highly unlikely to experience exceptionally severe rainfalls exceeding 250mm in a day. Nevertheless, short series events still necessitate preparedness and preventive action. It's crucial to note, however, that our models have limitations. Among the primary oversights is the exclusion of several potentially influential variables, such as temperature and geographical factors, which can significantly impact precipitation patterns.

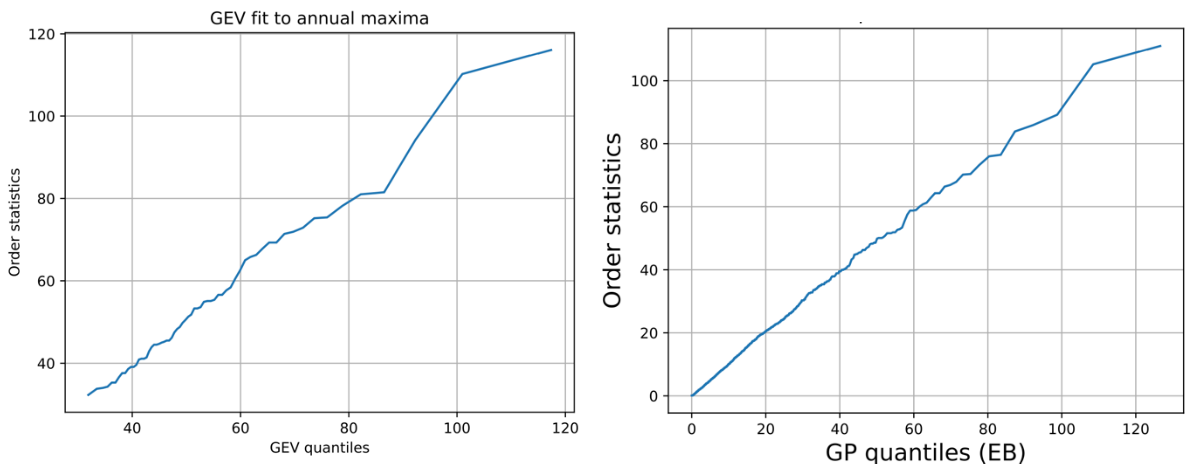

Figure 1. QQ-plot of GEV and GPD model