Characterizing Extreme Rainfall in Miami and Detroit

Characterizing extreme rainfall is essential for understanding precipitation patterns and preparing for major weather events. Extreme precipitation can have significant consequences, including flooding, infrastructure damage, and disruptions to local economies. This study focuses on characterizing the upper tail of rainfall distributions in Miami and Detroit, two geographically distinct regions in the United States. Given that some areas experience more extreme precipitation than others, comparing these regions provides insight into their differing rainfall characteristics and how local climatic conditions contribute to variations in extreme precipitation trends. Specifically, this analysis employs the Generalized Extreme Value (GEV) distribution to model extreme rainfall events, enabling a comparative assessment of their upper tail behavior and long-term accumulation trends. Understanding these trends can inform urban planning, disaster preparedness, and infrastructure development to mitigate the risks associated with extreme rainfall in specific areas.

This analysis utilizes daily rainfall data (in mm) from January 1, 1948, to the present for Detroit and Miami. Rainfall values range from 0 mm to approximately 380 mm. To visualize rainfall trends, time series plots (Figure 1) illustrate the temporal variation in precipitation. Miami exhibits more extreme rainfall events, with peaks exceeding 350 mm, whereas Detroit's rainfall rarely surpasses 120 mm. Differences in seasonal precipitation patterns, storm activity, and geographical influences contribute to the variation observed in these time series. Additionally, ratios of rainfall percentages over certain thresholds for each region can give an overall idea about extreme rainfall. With a threshold of 10 mm, Detroit had 7.32 percent of its days go above that mark. Miami rainfall patterns displayed an increased proportion over the 10 mm threshold of around 12.25 percent. Changing the threshold to 30 mm, Miami had around 3.97 percent of days at or exceeding that total accumulation whereas Detroit only had about 0.99 percent of days. Overall, this tells us that Miami has a larger ratio of heavier rainfall in this dataset.

To characterize extreme rainfall, this study applies the block maxima approach with the GEV distribution. The data is partitioned into annual blocks, with the maximum rainfall recorded each year used to model the distribution. According to the Fisher-Tippett-Gnedenko theorem, the maxima should follow a GEV distribution, a three-parameter family encompassing the Gumbel, Fréchet, and Weibull distributions. The shape parameter of the GEV model determines the tail behavior: higher indices indicate shorter tails and a lower likelihood of extreme values. The shape parameter can also give valuable insight as to what distribution the extremes can be characterized by. Specifically, if the parameter is less than 0, the distribution will follow a Weibull domain. This approach mitigates positive serial dependence, as only the largest annual values are considered. Despite the limited sample size of approximately 75, the method remains effective for estimating extreme rainfall behavior. However, we should be aware of the substantial decrease in sample size due to only taking a maximum from each year for this model. The block maxima approach ensures that each observation used in the model represents an independent extreme event, reducing biases that could arise from clustering of extreme rainfall occurrences within short time frames.

To assess model fit, QQ-plots compare empirical and theoretical quantiles, where a linear trend indicates a good fit. Additionally, return levels for 10, 100, 500, and 1000 years are estimated to project long-term rainfall accumulation. These return levels provide estimates of the magnitude of extreme precipitation expected at various recurrence intervals, which are valuable for risk assessment and engineering applications.

The GEV analysis provides insight into the upper tail behavior of rainfall distributions in Miami and Detroit. Miami's shape parameter is approximately -0.2081, yielding a tail index of 4.804, while Detroit's shape parameter is -0.19008, with a tail index of 5.26. Both values indicate a Weibull domain of attraction, meaning that extreme rainfall is bounded. This suggests that although extreme rainfall events can occur in both regions, there is a natural upper limit to how extreme these events can be.

Long-term rainfall projections (Figure 2) reveal that Miami's extreme rainfall trends exceed those of Detroit. For instance, in 100 years, Miami’s rainfall accumulation is projected to be nearly triple that of Detroit. Additionally, Miami’s extreme rainfall increases more rapidly over time, indicating that the frequency and intensity of extreme precipitation events may become more pronounced. This finding aligns with previous climatological studies that highlight the role of tropical systems in driving Miami’s precipitation trends. The QQ-plots (Figure 3) confirm that the GEV model provides a good fit for both datasets, as indicated by their linear trends and minimal deviations. These plots validate the reliability of the GEV approach in characterizing extreme rainfall behavior for both locations.

The results highlight both similarities and differences in the extreme rainfall characteristics for Miami and Detroit. Both regions exhibit bounded extreme rainfall behavior, but Miami's more negative shape parameter suggests a heavier tail, implying a slightly higher probability of extreme rainfall compared to Detroit. This difference aligns with Miami’s susceptibility to tropical storms, which contribute to increased variability in extreme precipitation. The presence of tropical storms and hurricanes in southern Florida results in more frequent and intense rainfall events, leading to the observed differences in extreme rainfall distributions.

The return level estimates underscore the significance of regional differences in extreme rainfall trends. Miami's projections indicate greater uncertainty in extreme events, necessitating larger safety margins when planning for major rainfall occurrences. In contrast, Detroit’s rainfall extremes are more predictable, allowing for more confident estimation of upper bounds in planning scenarios. This suggests that urban planners in Miami must consider more adaptable and robust strategies for flood mitigation, whereas Detroit’s precipitation trends allow for more structured risk assessment frameworks.

While the GEV method effectively characterizes extreme rainfall, the limited number of annual maxima (approximately 75) constrains the analysis. Alternative approaches, such as the Generalized Pareto Distribution, which utilizes more data points, could provide additional insight into upper tail behavior. The GEV method assumes stationarity in extreme rainfall trends, meaning that past data is representative of future behavior.

Overall, the GEV analysis demonstrates distinct differences in extreme rainfall characteristics between Miami and Detroit. Miami exhibits greater variability and a higher long-term rainfall trend, whereas Detroit’s rainfall extremes are more stable. These differences should be considered when developing regional strategies for managing extreme precipitation events. Understanding these trends is crucial for improving resilience to extreme rainfall, particularly in coastal regions like Miami that are at greater risk of tropical storms and hurricanes.

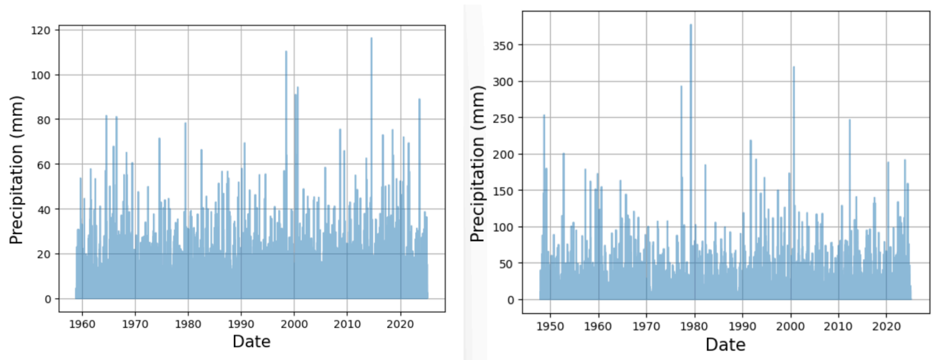

Figure 1: Time series plot of Detroit (left) and Miami (right) rainfall from 1958 to 2025.

Years	Miami Rainfall (mm)	Detroit Rainfall (mm)	Ratio (Miami/Det)
10	192.25	77.27	2.49
100	357.42	128.08	2.79
500	527.84	178.71	2.95
10000	620.64	205.73	3.02

Figure 2: Miami and Detroit rainfall accumulation trends based on GEV method by years.

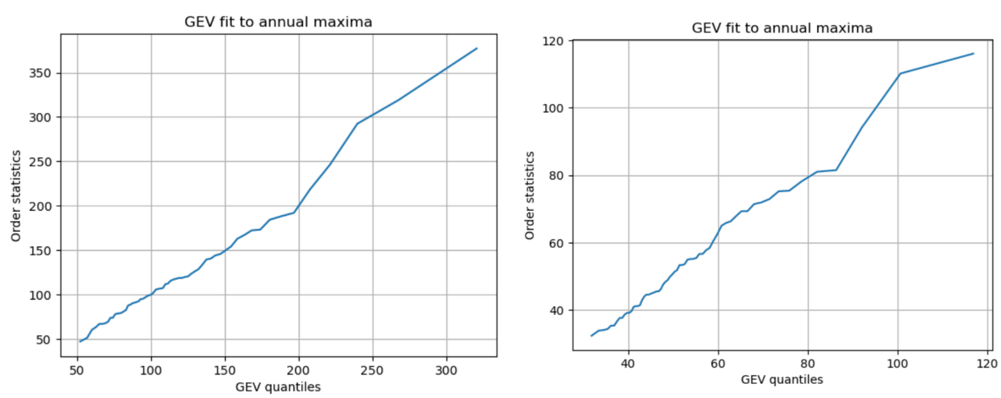

Figure 3: QQ-Plots for GEV model for Miami (left) and Detroit (right) data.

Focus	
Methods	
Writing	

Findings	