Analyzing Extreme Precipitation Events in Bloomington Using Generalized Extreme Value Regression

On June 18th and 19th, 2021, Bloomington encountered one of its most severe meteorological phenomena in a century, receiving a total of 6.1 inches of rainfall over two days. This extreme precipitation event triggered significant flooding and power outages, led to extensive property damage and loss of life, and set a record that marked a century (Askins, D., 2021; Richard, D., 2021). Analyzing such severe weather events is critical for understanding their impacts, forecasting future occurrences, and developing effective mitigation strategies.

The event was extensively covered in the media, highlighting the inundation of streets and bridges and the forced relocation of communities (Askins, D., 2021; McGerr, P., 2021). The reports also focused on emergency responses, including evacuation efforts and the endeavors of first responders, underscoring the substantial effects on human lives and the economy (Legan, M., 2022).

The flooding was precipitated by significant rainfall from a Mesoscale Convective System (MCS), associated with a quasi-stationary front. On the night of June 18th, the MCS intensified and remained stationary (NOAA, 2021), resulting in a large-scale thunderstorm that lingered over the Bloomington area in Indiana for more than eight hours, continuing into June 19th. Throughout this period, multiple thunderstorm cells repeatedly developed and moved across the same location (Travis, 2021). A local weather station recorded more than 10,000 lightning strikes within a 30-mile radius overnight (Travis, 2021).

When compared with historical weather data from Bloomington, the extremity and anomaly of this rainfall are evident. The 6.1 inches of rain far exceeded expectations and serve as a crucial case study for understanding regional climate changes and their potential triggers.

Broad studies on similar extreme precipitation events in the United States show that climate change has already increased the frequency and intensity of extreme precipitation across the country (IPCC, 2021), potentially raising the probability of observed rainfall by at least 3.5 times (Risser and Wehner, 2017). Further research indicates that the intensity and frequency of extreme precipitation in the Midwest are on the rise, primarily due to increased moisture transport and precipitation under specific circulation patterns (Papalexiou et al., 2019; Davenport et al., 2021).

Human activities, particularly the emissions of greenhouse gases and aerosols, have significantly altered precipitation patterns. Studies show clear anthropogenic signals in the intensification of extreme precipitation events, where greenhouse gases have markedly increased daily extreme precipitation, slow-reacting aerosols have generally contributed negatively across most regions, and fast-reacting aerosols exhibit seasonal variation in their impacts (Risser et al., 2024). These activities have shortened the recurrence interval of what used to be centennial events to once every 20 years, quintupling the risk (Kirchmeier-Young et al., 2020).

The IPCC's 2021 report forecasts that the intensity and frequency of extreme precipitation events will continue to rise (Seneviratne et al., 2021). This trend underscores the necessity of developing robust climate adaptation strategies and enhancing predictive technologies to mitigate future impacts.

Non-stationary GEV regression is an effective method for analyzing extreme events, focusing on the tails of data distributions. This approach captures the probability, intensity, and recurrence intervals of extreme precipitation events and is particularly apt for studying rare but impactful events like Bloomington's 2021 incident. In contrast, ordinary linear regression, which is suited for trend analysis of averages, fails to effectively assess the characteristics and risk changes of extreme events.

Analyses using non-stationary GEV regression on data from 1950 to 2022 estimated the 2021 event's recurrence interval at 86.57 years, compared to 249.36 years in 1950, indicating a significant shortening over the past 70 years. The risk ratio is about 2.88 times higher than it was 70 years ago. Analysis from 1895 to 2022 showed a return interval of 46.65 years for 2021, compared to 43.49 years for 1950, influenced by two extreme events in the early 20th century that each recorded about 7.8 inches over two days. These results highlight the sensitivity of findings to the choice of time series data. Shorter time series reflect contemporary climate risks more accurately, whereas longer series are influenced by early extreme events. Careful selection of datasets according to specific research objectives is essential, and results must be cautiously interpreted to avoid inaccurate conclusions due to biases in time series selection.

The 2021 Bloomington extreme precipitation event exemplifies the increasingly frequent and severe trend of such weather phenomena, driven in part by anthropogenic activities. The analysis using non-stationary GEV regression provides reliable estimates of risks and recurrence intervals, offering invaluable insights for policymakers and researchers. Future research must continue to integrate and refine these methodologies to better understand and predict extreme weather patterns, thereby ensuring communities are better prepared and responsive to these escalating threats.

The video can be found at https://www.youtube.com/watch?v=HsKcfD-3RKs
Code availability: https://github.com/Gong001/EAS-G-577/blob/main/major_assignment_GG.ipynb

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