

Extreme Value Theory for Climate-Related Environmental Disaster Risk Analysis: A Review of Urban Impacts and Vulnerabilities

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Abstract: Climate change is a major contributing factor to environmental disasters, frequently increase the risk and vulnerability of urban areas to various hazards. Appropriate methods for analysing climate change indicators are essential for developing risk management strategies in urban areas. Extreme Value Theory (EVT) provides a robust statistical framework for modelling and predicting rare, high impact events, making it essential for assessing climate-related risks. This review examines the application of EVT in analysing environmental disasters triggered by climate change, focusing on the Block Maxima (BM) method and Peak Over Threshold (POT) approaches, with an emphasis on assessing urban impacts and vulnerabilities. Through a comprehensive literature review, this paper highlights EVT's growing importance in predicting extreme climate events in cities, underscoring its value for researchers, policymakers, and disaster risk managers that are important for urban adaptation strategies. The findings confirm the effectiveness of EVT in reliably modelling and predicting extreme environmental events, indicating its competence to obtain accurate risk estimates that reflect observed extreme events through its return period calculations. The BM is beneficial for determining absolute extremes, while POT provides more detail about threshold-exceeding extreme events. EVT describes an essential framework for modelling extreme environmental disasters exacerbated by climate change, enabling the development of adaptive strategies to reduce urban impacts and vulnerabilities.

Keywords: climate change; environmental disaster; extreme value theory; risk analysis; urban impacts; vulnerability

1. Introduction

The world is confronted with the phenomenon of climate change. In fact, climate change has led to the occurrence of many natural disasters that caused high impacts and vulnerability in cities. The most important climate phenomenon on Earth, the El Niño Southern Oscillation (ENSO), a cyclical climatic phenomenon marked by temperature changes in the central and eastern tropical Pacific Ocean, is influenced by climate change. ENSO events have significant global ramifications, underscoring the importance of comprehending their reactions to human-induced warming (Cai et al. 2021). The extreme phases of the ENSO cycle are represented by El Niño and La Niña. In conjunction with warming-induced changes in ENSO, this intensified cycle results in more frequent and severe ENSO-related droughts, floods, heatwaves, wildfires, and severe storms (Mcphaden 2023). According to OCHA (coordinates the global emergency response to save lives and protect people in humanitarian crises) (Reliefweb 2023), climate-related disasters resulted in the loss of 12,000 lives worldwide. Estimation of disaster risk



parameters through appropriate disaster risk analysis is an important aspect in disaster management (Oktaviana and Fithriasari 2023). Climate conditions strongly affect urban environments, which under climate change are expected to further intensify urban impacts (Carbonari et al. 2025). Climate-related environmental disaster management is very important to increase flexibility and mitigate the vulnerability of communities in urban sectors due to the negative influence of climate change as explained in Goal 13 of Sustainable Development Goals (SDGs), Climate Action (Liu et al. 2023; Oktaviana et al. 2025; Prasad and Raturi 2025; Solangi and Magazzino 2025). This explanation indicates that climate change should be taken seriously.

Natural extreme events resulting from climate change are known as hazardous events, which is occurring infrequently but capable of causing significant damage. These events often result in widespread impacts and cause significant economic and social ramifications (Hamdi et al. 2021). Extreme Value Theory (EVT) provides a statistical framework for analysing the behaviour of rare events, making it a valuable tool for understanding and predicting climate change disasters. Extreme climate scenarios are highly relevance for impact researchers, the modelling community, and other stakeholders concerned with climate change impacts and strategies for adaptation (Goldstein et al. 2002). The study of climate science is one of the primary areas where EVT is applied. Although the likelihood of extreme events resulting from climate change has decreased swiftly, the resulting damage and the cost of protecting against them have also increased rapidly (Toulemonde et al. 2015).

Several studies on EVT for the analysis of climate change and environmental disasters have been conducted, such as: Benetazzo et al. (2021) applied EVT to study spatio-temporal maximum sea wave heights during cyclone winds in the Northwestern Pacific. By selecting a threshold for extreme wave height, they were able to model the exceedance probability. Kim et al. (2021) conducted an evaluation of the temporal probability of rainfall-triggered landslides in Inje Korea using nonstationary extreme value analysis. This finding demonstrates that climate change causes rainfall patterns to change over time. Hamdi et al. (2021) reported that the characterization of extreme values requires lengthy and consistent time series data, which may not be available for certain variables or geographical regions. The research of Ali et al. (2022) offers valuable insights into the beneficial influence of interconnected environments on the safety of compulsory lane-changing manoeuvres and validates the accuracy of EVT models in predicting crash risk based on traffic conflict data. Radfar et al. (2023) reviewed research challenges and future directions for nonstationary extreme value analysis and obtain that nonstationary EVT is more suitable for environmental data analysis. Many studies have discussed the application of EVT, but this paper offers a novelty regarding the application of EVT that focuses on urban impacts and vulnerabilities caused by environmental disasters due to extreme climate change. This paper provides an overview of EVT applications for extreme events, especially those related to climate change, which contribute to environmental disasters and pose significant impacts and vulnerabilities in urban areas.

2. Review Methodology

This research systematically reviewed an extensive collection of Scopus literature in ScienceDirect containing significant keywords associated with Extreme Value Theory (EVT) and its applications in analysing environmental disaster risk stemming from climate change. The utilization of the Scopus database in ScienceDirect is based on its reputation as a dependable repository of scholarly and scientific publications, and all retrieved bibliographic data were managed and organized using Zotero reference manager to ensure systematic collection and accuracy. The search strategy involved the use of the keyword phrase “extreme value theory for climate change” to capture a wide range of studies related to EVT and extreme events. This keyword is based on previous considerations, which were provided in the introduction, that climate change leads to environmental disaster. Therefore, the keyword “environmental disaster” is not used for the search. Articles were filtered based on the following inclusion criteria: (1) peer-reviewed research published in the last five years (2020-2024) to ensure the inclusion of the most up-to-date findings, methodologies, and applications of EVT in relation to climate-induced environmental disasters; (2) focus on environmental sciences and earth/planetary sciences; and (3) the studies applying EVT in the context of climate-induced natural disasters such as floods, heatwaves and landslides. The open-access publications are selected to ensure accessibility.

The selection criteria were based on relevance to the research questions, novelty of application and geographical diversity, with a particular focus on regions heavily impacted by climate change. Studies that did not meet these criteria, including those focusing on other applications of EVT (e.g., finance or engineering without environmental relevance), were excluded from this review. This review focuses on two approaches of EVT, that are Block Maxima (BM) and Peaks Over Threshold (POT). The BM method is connected to Generalized Extreme Value (GEV) distribution, while the POT method is connected to Generalized Pareto Distribution (GPD). This review describes how the two approaches are used to analyse the extreme climate change indicators that cause environmental disaster.

3. Literature Review

The review analysis is divided into 4 sections. Section 1 provides bibliometric analysis that contains information about selected documents related to the topic. Section 2 provides information about climate change related to environmental disasters. Section 3 provides EVT methods for disaster risk analysis caused by extreme climate change indicators. Section 4 provides limitations of EVT in climate change analysis related to disaster risk.

3.1. Bibliometric Analysis

By using the literature review method as explained in the review methodology, the 3,441 related documents were obtained, and the authors used 500 relevant documents according to the highest search results. These 500 documents were analysed by using bibliometric analysis via R software. The bibliometrix package and biblioshiny interface in R software provide comprehensive visualization and analytical capabilities for mapping scientific knowledge, identifying research trends, and analysing publication patterns (Sasmita and Ratih 2024). Based on those 500 documents, a thematic map was created in Figure 1.

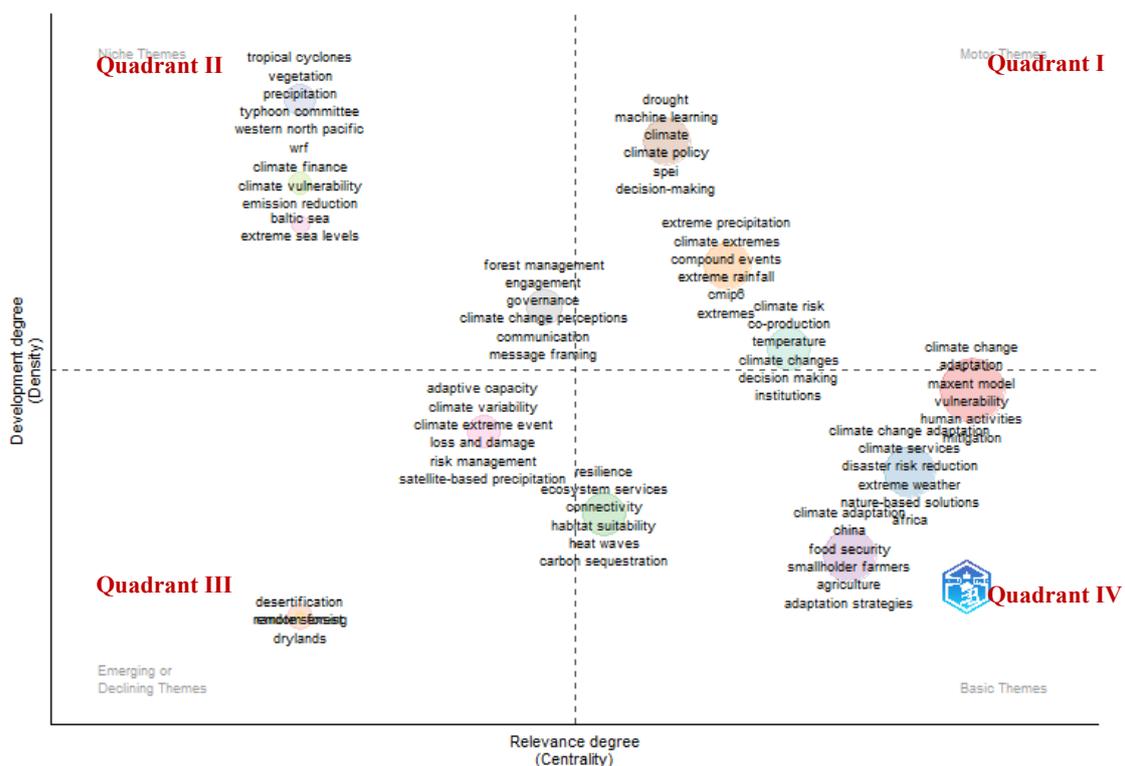


Figure 1. The Mapping of Topic Related to EVT for Climate Change (Author).

Figure 1 presents the mapping of topic related EVTs for climate change to describe the relation of centrality and density, that is divided into four Quadrants, that are: Quadrant I for topics with high centrality and density; Quadrant II for topics with high centrality and low density; Quadrant III for topics with low centrality and high density; and Quadrant IV for topics with low centrality and density. The topics located in Quadrant I (the upper right quadrant) require additional development and study because of their high centrality and density, like “drought”, “machine learning”, “climate”, “climate policy”, “decision-making”, “extreme precipitation”, “climatic extremes”, “compound events”, “extremes”, “climate risk”, “temperature”, “climate change” and the topics shown in this quadrant. While the topics in Quadrant IV (the lower right quadrant) are highly relevant but have not receive extensive research attention, like “climate change adaptation”, “disaster risk reduction”, “extreme weather”, “adaptation strategies”, “climate services”, “nature-based solution”, “ecosystem services”, “resilience”, and the topics shown in this quadrant. Based on this topic mapping, this review article is suitable for anyone who needs some overview of those topics in the upper and lower right quadrants, as explained previously.

A ranking of 10 journals was made ordered by the journals that published the most articles on the topic of EVT for climate. It is presented in Figure 2.

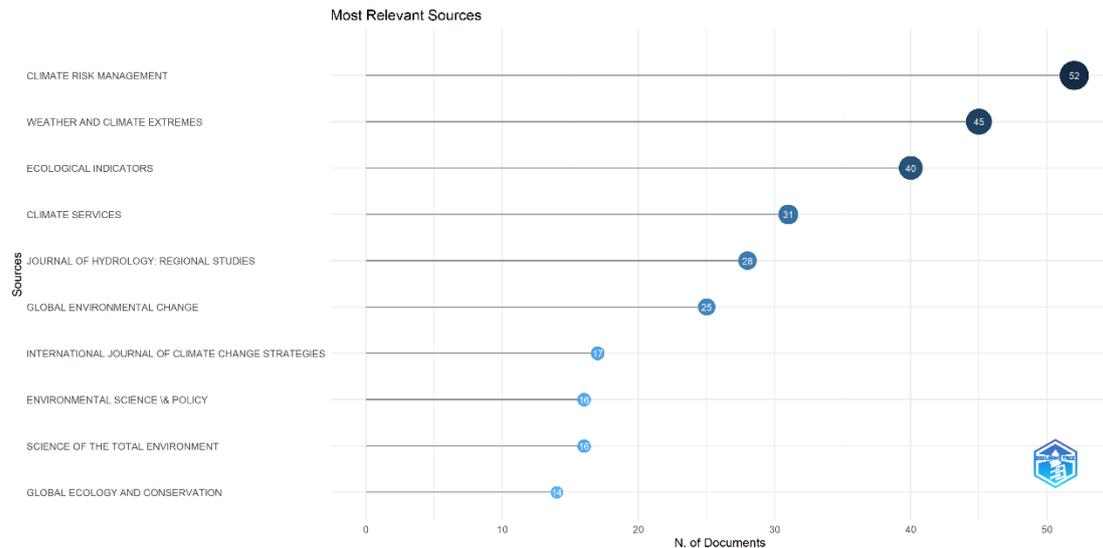


Figure 2. The 10 Journals that Frequently Publish Articles on the Topic of Extreme Value Theory for Climate Change (Author).

Climate Risk Management is the journal that publishes the most articles on EVT topic analysis for climate change, with 52 of the 500 articles in total. The next journal is Weather and Climate Extremes, with 45 of 500 articles in total. Ecological Indicators published 40 articles. The other journals can be identified in Figure 2. The last ranking is Global Ecology and Conservation with 14 articles published. In the next section, the theories of EVT and climate change related to environmental disaster risk will be explored by using some papers on the sources of the 10 highest-ranking journals in Figure 2.

3.2. Climate Change Related to Environmental Disaster

Climate change affects many fields worldwide. It also endangers the health and well-being of individuals (NOAA 2024). Slovic et al. (2024) examined the prevalence of climate hazards in 124 Latin American cities and described how urban social and built environments influence these hazard and adaptation efforts. This study highlights the need for a comprehensive urban extreme climate vulnerability assessment and appropriate adaptation strategies to effectively address the challenges faced by cities in the context of climate change. Stefkovics et al. (2024) explained that climate alters convictions that drive person activities. The securitization of climate change has driven different political and approach reactions, highlighting the need for viable hazard administration and adjustment techniques (Englund and Barquet 2023). Parsons et al. (2024) highlighted the growth in climate justice publications, particularly in Northern Hemisphere, and argued for the need for policies that impact climate change on vulnerable urban population. The study suggests effective climate action strategies. It is important to assess and mitigate the impacts of climate change related to environmental disasters (Attoh et al. 2022). Various methodologies were conducted to assess climate risk, like impact chain methodology (Zebisch et al. 2022; Lücknerath et al. 2023), probabilistic frameworks utilizing probability density function (Watterson 2008; Fronzek et al. 2022) and engaging stakeholders and scientists in collaborative work (André et al. 2023). This methodology plays a vital role in urban policymaking and planning, enabling the development of appropriate strategies to reduce environmental disaster risks and increase urban resilience to extreme climate change.

3.2.1. Climate Change Indicators: Rainfall and Temperature

Climate change has the potential to escalate the frequency and severity of environmental disasters, particularly through its effects on indicators like rainfall and temperature (based on related topics in upper and lower right quadrant in Figure 1). Increasing global temperatures can alter rainfall patterns, leading to more frequent extreme floods and droughts (Bolan et al. 2024). This section examines the impacts of rainfall and temperature, highlighting their significance in the context of environmental disasters.

Rainfall refers to the depth of rainwater falling on the ground or a flat surface, if no evaporation, infiltration, or runoff occurs. A rainfall measurement of 1 mm indicates that rainwater with a height of 1 mm has fallen on a surface area of 1 m² under these same assumptions (Mulyono 2016). Heavy rainfall can lead to minor or severe flooding, posing significant risks to human life. Additionally, residents in mountainous regions face an increased risk of landslides. Severe weather conditions can also cause

damage to property and infrastructure (Mozter 2023). Understanding the link between rainfall and the likelihood of environmental disasters, such as floods and landslides, is essential from both practical and theoretical viewpoints. The design storm method in engineering forecasts a hydrograph characterized by a particular peak discharge probability utilizing synthetic rainfall events of corresponding probability, applying a rainfall-runoff model (Breinl et al. 2021). The distribution of extreme rainfall is shaped by the climatic conditions of a given location. Research indicates a positive correlation between expected extreme rainfall and average annual rainfall, based on analysis of hourly and daily rainfall data from various climatic regions, including the United States, Australia, the British Isles, Japan, India, and peninsular Malaysia (Barbero et al. 2019). In different regions, these rare extreme events may be linked to climate phenomena such as ENSO or unusual atmospheric conditions that promote convection (Piper et al. 2016). Typically, in areas with frequent short convective rainfall frequency curves, there are more humid regions with longer rain showers. The interaction between the statistical characteristics of extreme rainfall and the processes within catchments that form flood and landslide frequency curves is a fascinating subject from a theoretical standpoint. In a hypothetical scenario of rectangular rainstorms with fixed durations, constant event runoff coefficients, and unchanging routes, the distribution functions of flood peaks and rainfall intensities are directly related. However, in real-world scenarios with various storms and catchments, multiple factors cause the distributions of flood and landslide frequencies to diverge from those of rainfall (Mulyono 2016). A reliable rainfall threshold can be established by using EVT (Karimah et al. 2019).

Warming has significantly impacted the frequency and variability of natural disasters worldwide (Zhu and Fan 2021). According to the United States Geological Survey (USGS), rising global surface temperatures are likely to lead to more frequent droughts and intensified storms (USGS 2024). The increased evaporation of water into the atmosphere supplies additional energy for the formation of stronger storms. Higher atmospheric and ocean surface temperatures can result in stronger wind speeds during tropical storms. Additionally, rising sea levels now expose previously unaffected higher elevations to the erosive effects of waves and currents typically associated with the sea. Trenberth et al. (2014) noted that expanding drought conditions are driven by increased evapotranspiration due to the additional heat in the climate system. They also reported that higher temperatures led to more frequent, intense, and prolonged extreme events, such as heatwaves and floods. Furthermore, the melting of snowpacks and glaciers is accelerating, along with an increase in heavy rainfall events.

3.2.2. Environmental Disaster Triggered by Climate Change

Environmental disaster can be attributed to hazards, either directly or indirectly. Hazards is a process or phenomenon that cause impacts such as human and economic losses, ecological degradation, social disruption, and damage of environmental resources (UNDRR 2017; Shi 2019). Hazards include environmental, biological, geological, hydrometeorological and hydrodynamic features, as well as human activities like industrial and urban development (CDEMA, 2014; UNDRR, 2017). Rohmer et al. (2021) highlighted the significance influence of climate change indices, like North Atlantic Oscillation, on extreme sea level events, underscoring the role of climate change in triggering environmental disasters in coastal urban areas. The work result that by identify specific climate drivers of extreme sea levels, the policymakers and urban planner can be developed to make adaptation and mitigation strategies of the environmental disaster's impacts on vulnerable coastal cities. Global climate change is characterized by prolonged changes in average climatic factors, especially mean temperature, and in the pattern of extreme weather events (Angra and Sapountzaki 2022). These climate shifts are expected to intensify the effects of forest fire and floods (Touma et al., 2022; Xu et al., 2023).

Shin and Park (2023) introduced statistics distribution to model climate extremes. Accurate modelling of such extreme events is critical for effective disaster response planning and the development of resilient infrastructure in urban areas vulnerable to environmental hazards. This is in line with (Zeder and Fischer 2024) who show that extreme event modelling is important for the application of infrastructure design and insurance related to environmental disasters due to extreme climate. Building on these perspectives, it is recommended to integrate data from multiple research sites on urban impacts to enhance the robustness of extreme value modelling and to more effectively capture the unpredictable nature of long-term variability. Accurate modelling of climate extremes is particularly critical in urban areas, where high population density and concentrated assets increase vulnerability to hazards, such as floods, heatwaves and the others. Recent studies have shown that multiple sites approach not only reduce uncertainty but also capture spatial dependencies in extreme climate indicators across urban areas (Bárdossy and Pegram 2009; Yang et al. 2016).

3.3. Extreme Value Theory (EVT) Method in Climate Change Analysis Related to

Environmental Disaster Risk

EVT is frequently used to evaluate the extreme behaviour of environmental processes (Ebrechts et al. 1997). In the context of climate risk management and the study by Lang and Poschlod (2024), EVT is used to model and predict the probability of extreme weather events, such as heavy rainfall or flash flooding. By analysing the distribution of past extreme events, EVT helps in estimating the likelihood and potential impact of future extremes, which is essential for risk assessment and pricing, updating hazard models, identifying risk regions, and quantifying changes in risk. By using EVT, one can estimate the probability of rare events even beyond the range of observation. For instance, the return levels associated with return periods longer than the available observation period can be estimated (Rivoire et al. 2022). While the data vary over time, nonstationary EVT is needed.

There are two classical approaches for EVT, that are Block Maxima (BM) and Peak Over Threshold (POT) (Ebrechts et al. 1997; Coles 2001). The BM method consists of segmenting the data into equal-length, non-overlapping time periods, allowing for inference under the premise that either the maximum or minimum value within each segment conforms to the Generalized Extreme Value (GEV) distribution (Katz et al. 2002). Katz et al. (2002) confirm that the GEV distribution can be effectively describe the maxima and the tail properties of the underlying data. More information about the GEV distribution is provided in the methods section of this paper. On the other hand, the POT method requires establishing a threshold to separate extreme data points from the overall dataset, with inference based on the assumption that the data points that surpass this threshold adhere to a Generalized Pareto Distribution (GPD) (Beirlant et al. 2004; Afuecheta and Omar 2021).

3.3.1. Block Maxima (BM)

The limiting distribution for large blocks is the Generalized Extreme Value (GEV) (Beirlant et al. 2004; Huang et al. 2021). The block maxima model is an approach that identifies extreme values by taking the maximum values within specific data blocks. The illustration of the block maxima method can be seen in Figure 3. It shows a plot of the rainfall (mm/day) over time, where the maximum value of each block is the extreme rainfall (indicated by the blue arrow). This approach yields a single extreme value for each block. One drawback of the block maxima method is the potential loss of data since it generates only one extreme value for each block (Beirlant et al. 2004; Rinaldi 2016).

The Cumulative Distribution Function (CDF) of GEV is written as (Gnedenko 1943; Pal et al. 2023):

$$G(x) = \begin{cases} \exp\left(-\left[1 + \xi\left(\frac{x - \mu}{\sigma}\right)\right]^{-1/\xi}\right), & \xi \neq 0 \\ \exp\left(-\exp\left(-\frac{x - \mu}{\sigma}\right)\right), & \xi = 0 \end{cases} \quad (1)$$

μ = the location parameter, σ = the scale parameter and ξ = the shape parameter. A positive value of the shape parameter indicates a heavy-tailed distribution. This means that if $\xi = 0$, $\xi > 0$, and $\xi < 0$, the distribution $G(x)$ corresponds to the Gumbel, Fréchet, and Negative-Weibull distributions, respectively (Afuecheta and Omar 2021).

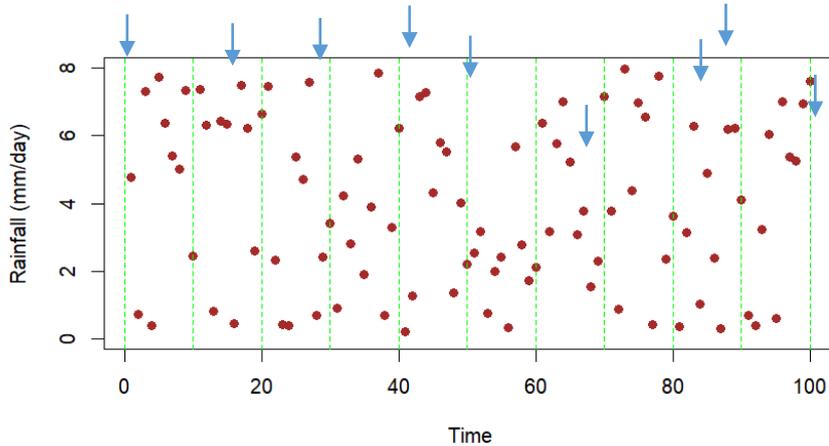


Figure 3. The Illustration of Block Maxima (Author).

The GEV distribution is essential for understanding the statistical behaviour of extreme values in

climatology (Chan et al. 2023). In a stationary GEV model, all the parameters are kept constant. However, when the distribution of extreme events is expected to vary over time, the GEV parameters can be adjusted to be time dependent. In the nonstationary GEV, the location parameter is modelled as a first-degree linear function of time (Pal et al. 2023). Nonstationary extreme value analysis is used to address the evolution of extremes over time and their connection to climate variability. This approach involves the use of nonstationary GEV distribution where parameters (location, scale, and shape) can vary as functions of covariates such as climate indices (Rohmer et al. 2021).

Return levels are high quantiles of the GEV distribution, representing the threshold exceeded with a specific probability. Return periods are the inverse of the exceedance probability, indicating the average interval between events exceeding the return level (Coles, 2001).

3.3.2. Peak over Threshold (POT)

This method is used to model values that exceed a certain high threshold using the Generalized Pareto Distribution (GPD). The GPD is suitable for describing the tail behaviour of distributions, particularly for extreme values beyond the threshold (Afuecheta and Omar 2021; Moccia et al. 2021). All values exceeding the threshold or above the threshold value are identified as extreme values. Figure 4 shows the illustration of the peak over threshold. It describes a plot of the rainfall (mm/day) over time, where values above the threshold (indicated by the green line) are extreme rainfall.

The CDF of the GPD is as follows (Coles 2001; Sanderson et al. 2023):

$$H(x) = 1 - \left[1 + \xi \left(\frac{x - u}{\sigma_u} \right) \right]^{-1/\xi} \quad (2)$$

The scale (σ_u) and shape (ξ) parameters of the GP distribution are estimated using maximum likelihood estimation (Shin and Park 2023). These parameters represent the rate of which extremes change with an increasing return period (Sanderson et al. 2023).

A suitable threshold u is selected to ensure that values above this threshold can be accurately shown by the GPD. Coles (2001) obtained that the thresholds for each season were established through Mean Residual Life (MRL) and Threshold Choice (TC) plots. In the MRL plot, the average of the excesses ($x - u$) above a threshold u is plotted against the threshold itself. The suitable range for threshold values is indicated by an approximately linear section. In the TC plots, the rescaled scale parameter $\sigma^* = \sigma_u + \xi u$ and the shape parameter ξ are plotted against the threshold. Both parameters should demonstrate relatively constant values across the range of valid thresholds.

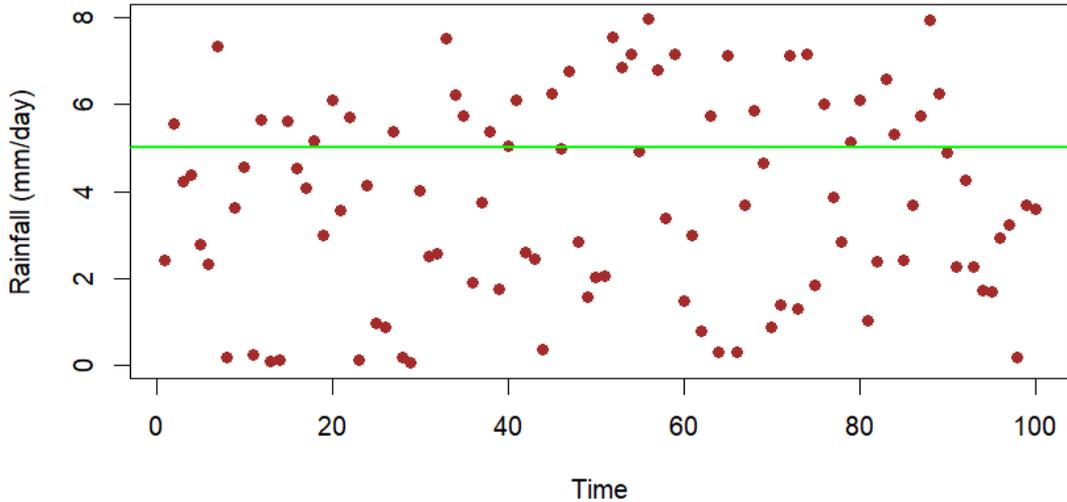


Figure 4. The Illustration of Peak Over Threshold (Author).

The BM method divides time-series data into several blocks, then takes the maximum value from each block. These maximum values are then used to model the GEV distribution, thereby estimating the probability of extreme events outside the observed data. BM is suitable for analysing climate indicator data that contain extreme values in each block, contain few zero values, and have upper extreme values. The block division needs to be adjusted to the available data. Unlike the BM method, which focuses on the maximum value within a fixed time interval, the POT method is applied by considering all values exceeding a certain threshold. This approach generates more data points for analysis, especially when

extreme events occur relatively frequently. For a sufficiently high threshold, the distribution of values exceeding that threshold can generally be approximated by the GPD. Thus, the POT method allows modelling the behaviour of the distribution's tails through the GPD parameters. Compared with the block maxima method, this method utilizes more data, potentially making the resulting estimates more reliable. Furthermore, this approach also provides an important framework for understanding the extreme characteristics of a distribution.

3.4. Limitations of EVT in Climate Change Analysis Related to Disaster Risk

Although EVT is a powerful tool for assessing extreme climate events, it is not without limitations. The accuracy of EVT depends heavily on the availability and quality of long-term observational data. For many regions, particularly developing countries, such data is often sparse or inconsistent, limiting the robustness of EVT applications (Hamdi et al. 2021). The limited data on disasters related to extreme events is also a significant issue that of course requires the addition of other external data so that analysis using EVT produces accurate results (Rutgersson et al. 2022; Truong et al. 2024). The selection of thresholds in determining extreme values contains subjectivity so that high precision is required, especially if there is a strong non-linear relationship between the selected extreme value model and the independent peaks, resulting in the possibility of errors occurring (Tancredi et al. 2006; Kuswanto et al. 2015; Huang et al. 2024). For the use of distribution in EVT, GPD can be adjusted to extreme data using Maximum Likelihood Estimation (MLE) (The Actuarial Education Company 2019) and GPD is unreliable to describe the data accurately if the convergence problem occurs when MLE is done (Chen et al. 2024).

Additionally, EVT assumes that past extremes can predict future events, but climate change introduces non-stationary into environmental systems. This non-stationary means that the statistical properties of extreme events may change over time, violating one of the core assumptions of EVT. While some studies like Radfar et al. (2023) have proposed non-stationary models of EVT, these approaches remain complex and are not yet widely adopted in the context of climate disasters. Finally, the choice of thresholds in the POT method can significantly influence the results and improper threshold selection may lead to inaccurate extreme event predictions (Moccia et al. 2021).

4. Discussion

The outcomes of this review study describe that EVT provides essential framework for modelling climate change related to environmental disaster, helping to design adaptive strategies that mitigate urban risks. This paper presents a comprehensive review of the application of EVT in analysing extreme events, particularly those related to climate change, which contribute to environmental disasters and cause significant impacts and vulnerability in urban areas. The results of this review provide important information regarding appropriate methods for analysing indicators of extreme climate that cause environmental disasters resulting in urban impacts and vulnerabilities. Using EVT, a suitable model was obtained for extreme climate indicators that cause environmental disasters in urban areas. This model can be used for risk analysis, the results of which can be used to develop adaptation and mitigation strategies in urban areas to deal with environmental disasters caused by climate change.

Environmental disaster risk analysis using EVT involves assessing the probability of extreme events, such as floods, landslides, or forest fire, occurring beyond what is considered normal or expected. EVT is a statistical method specifically designed to model the tail behaviour of extreme events in probability distributions. By analysing historical data on extreme events, EVT allows for the estimation of the likelihood of rare but potentially catastrophic events happening in the future (Ali et al. 2022; Rivoire et al. 2022; Chan et al. 2023). In disaster risk analysis, EVT helps identify the maximum probable magnitude of a disaster and the associated probabilities, which are crucial for decision-making, disaster preparedness, and risk mitigation efforts (Rivoire et al. 2022; Chan et al. 2023). Table 1 contains a summary of several studies on EVT in the application of environmental disaster risk analysis due to climate change as well as on its urban impacts and vulnerabilities.

Table 1. The Applications of EVT in Climate-Related Environmental Disaster Risk Analysis and Its Role in Urban Impacts and Vulnerabilities.

Researcher s (Year)	Methods	Environmental Disaster	Climate Factor	Urban Impacts and Vulnerabilities	Results of Application of EVT
Afuecheta and Omar (2021)	Trend Analysis and EVT (BM and POT)	Floods and Droughts in Africa	Rainfall and Tempera ture	Increasing extreme rainfall and temperature conditions pose significant challenges for urban areas, as increased rainfall can lead to severe flooding, while rising temperatures can worsen heat waves, strain infrastructure, and impact public health.	There is significant variability in rainfall and temperature extremes in the Horn of Africa. This includes fluctuations in the intensity and frequency of extreme events. The study's findings underscore the need for urban planners and policymakers to develop adaptive strategies that increase cities' resilience to the increasing risks associated with climate change-related environmental disasters.
Benetazzo et al. (2021)	EVT (BM) spatio- temporal	High waves due to cyclones in the Northwest Pacific	Wind speed	Cities are vulnerable to extreme waves, exacerbated by climate change, which increases the risk of storm surges, threatening ports, transport networks and low-lying settlements.	These findings offer insight into the occurrence of extreme waves during cyclones. To investigate the physical mechanisms underlying the occurrence of extreme waves in different regions around cyclones, they also explored regions where nonlinear four-wave interactions are more likely to occur by comparison.
Kim et al. (2021)	EVT (BM)	Landslide in Inje, Korea	Rainfall	In urban areas, landslides triggered by extreme rainfall can lead to severe infrastructure damage,	It results in comparison of landslide probability in Inje Korea for the next 7 time periods using the Non- Stationary Extreme Value method produces higher values compared to those obtained using

				disruption of transportation networks, and loss of life, particularly in cities with steep slopes and inadequate drainage systems.	the Stationary Extreme Value method. This shows that climate change causes rainfall patterns to change over time (non-stationary).
Rohmer et al. (2021)	Non-stationary EVT (BM)	Tides of sea water in coastal areas	Sea level and climate variability	In coastal urban areas, extreme sea levels can amplify tidal flooding, increasing the frequency and severity of storm surges that threaten infrastructure, transportation networks, and residential zones.	The study found that climate variability has a significant influence on the occurrence of extreme sea level events. Non-stationary models provide more accurate estimates of extreme sea levels than stationary models.
Park et al. (2022)	EVT (BM) and Probabilistic Approach	Landslide in Jinbu, Korea	Rainfall	The study's findings indicate that urban areas with steep terrains and intense rainfall are particularly susceptible to rainfall-induced landslides, which can lead to significant infrastructure damage, loss of life, and economic disruptions.	It is important to check stationarity in rainfall data carefully. Rainfall in this study area has a non-stationary trend. Landslide probability in Jinbu Korea for the next 4 time periods is obtained and used as a mitigation effort in landslide disaster evaluation.
Rivoire et al. (2022)	EVT (POT)	Extreme rainfall disaster in Europe	Rainfall	The study found that understanding the spatial	This study estimates the high recurrence rate of daily rainfall in Europe more accurately using

				<p>distribution and frequency of extreme precipitation is crucial for urban planning and disaster risk management, as such events can trigger landslides, especially in areas with steep terrain and inadequate infrastructure.</p>	<p>extreme value distributions. The results show significant variation in the return rate of extreme rainfall across different European regions, highlighting the importance of a regional approach in disaster planning and mitigation.</p>
<p>Chan et al. (2023)</p>	<p>EVT (BM and POT)</p>	<p>Floods in United Kingdom</p>	<p>Rainfall</p>	<p>Urban flooding resulting from extreme rainfall can have severe consequences, especially for vulnerable communities. In many cities, rapid urbanization has led to the development of informal settlements in flood-prone areas, increasing the exposure and sensitivity of these populations to flood hazards.</p>	<p>Extreme rainfall projections could help improve the resilience of urban drainage infrastructure in the UK to climate change.</p>
<p>Azzahra et al. (2023)</p>	<p>Spatial EVT (BM) Max Stable Process-Schlatche r's Model</p>	<p>Floods in West Papua, Indonesia</p>	<p>Rainfall</p>	<p>Manokwari district in West Papua has a high risk of disaster due to extreme rainfall, while Kaimana and Fakfak districts have a medium</p>	<p>The results of the study using spatial EVT show that the return period for the next 2, 4, 6, 8, and 10 years for extreme rainfall in Manokwari, Kaimana and Fakfak districts is in the very heavy category. The</p>

				extreme rainfall-related disaster risk. If there is no adequate disaster management and mitigation efforts, this can endanger the lives of local communities.	return period value can be information that can be used by related parties to prepare disaster management and mitigation efforts, especially flood disasters due to extreme rainfall in these areas.
Nugroho and Oktaviana (2023)	Logistic Regression and EVT (BM and POT)	Forest and Land Fires in West Kalimantan, Indonesia	Temperature and Wind speed	Kubu Raya, Mempawah, Landak and Sanggau districts has a high vulnerability of forest and land fires. While Pontianak has high vulnerability of forest and land fires in a small part of its area and is not vulnerable in most of its areas.	The probability of forest and land fires in Kubu Raya, Mempawah, Landak, Pontianak and Sanggau districts in the next 1, 3 and 5 years are still quite high. The highest chance is in Sanggau District. The results of this probability calculation can be used to prepare an early warning system in each district to anticipate forest and land fires.
Sanjaya et al. (2023)	Spatial EVT (BM) Max Stable Process-The Smith and Brown-Resnick Model	Coastal hazard in Bali Indonesia	Sea current velocity	Extreme ocean current velocities in the waters of Serangan, Gianyar, Nusa Dua, and Nusa Lembongan, Bali, Indonesia, have moderate to strong current characteristics. The stronger the ocean current, the more destructive the	The estimated return level shows an increase in the maximum ocean current speed along with an increase in the number of the same return period. The estimated return level is included in the strong current category, especially in the Nusa Lembongan Waters exceeding 2 m/s. The results of the return level estimation of the Bali Sea current speed can be used by related parties for mitigation and prevention of other coastal disasters on the

				potential for coastal disasters caused. The velocity of the ocean current in South Bali is categorized as strong and causes the frequency of coastal disasters on the island of Bali to be quite high, especially in the southern part of the island of Bali.	island of Bali, especially South Bali.
Lang and Poschlod (2024)	EVT (BM) Ensemble Model	Flood disaster in several areas	Rainfall	High-intensity rainfall poses substantial challenges to urban environments, so that urban areas face amplified vulnerabilities, including damage to infrastructure, disruption of services, and threats to public safety.	The EVT ensemble approach can provide better insights into the impacts of climate change on extreme rainfall patterns, which is important for disaster risk planning and adaptation.
Zeder and Fischer (2024)	EVT (BM)	Environmental disasters associated with extreme rainfall in various regions globally.	Rainfall	The long-term variability of extreme precipitation events has implications for disaster risk in urban areas. Such environmental disasters, triggered by extreme rainfall, exacerbate	The study found that there are significant gaps in extreme rainfall data when viewed at decadal to century scales. This long-term variability has important implications for extreme value models used in extreme weather prediction.

				urban vulnerabilities by overwhelming drainage systems, increasing flood risks, and damaging critical infrastructure.
Oktaviana et al. (2025)	EVT (POT)	Floods In Jakarta, Indonesia	Rainfall	<p>Rainfall in Jakarta was detected to be very high, most often occurring in February, causing flooding which caused several houses and public facilities in Jakarta to be submerged.</p> <p>The study results state that the EVT method is very important for risk analysis on climate change and natural disasters. The results of the Probability calculation using EVT POT produce a probability close to 1 over a period of 50 years indicating that flooding due to extreme rainfall is almost certain to occur in the long term in Central Jakarta and North Jakarta. The potential for flooding in Jakarta is high, making it important to carry out disaster management and disaster mitigation efforts using the results of extreme rainfall threshold calculations which can be used as an early warning system.</p>

Based on some studies in Table 1, some environmental disasters were analyzed by using EVT (BM and POT), such as: floods (Afuecheta and Omar 2021; Azzahra et al. 2023; Chan et al. 2023; Lang and Poschlod 2024; Oktaviana et al. 2025), landslides (Kim et al. 2021; Park et al. 2022), other extreme rainfall disasters (Rivoire et al. 2022; Zeder and Fischer 2024), coastal hazards (Benetazzo et al. 2021; Rohmer et al. 2021; Sanjaya et al. 2023) also forest and land fires (Nugroho and Oktaviana 2023). The studies finding that EVT (BM and POT) plays a crucial role in analysis of environmental disaster risk caused by climate change that highlights several urban impacts and vulnerabilities, like: extreme rainfall leads to flood that increased infrastructure (Afuecheta and Omar 2021; Azzahra et al. 2023; Chan et al. 2023; Lang and Poschlod 2024; Oktaviana et al. 2025), landslide triggered by extreme rainfall can disrupt economies (Kim et al. 2021; Park et al. 2022), coastal city risk by rising of sea levels (Benetazzo et al. 2021; Rohmer et al. 2021; Sanjaya et al. 2023), the challenges in disaster preparedness (Rivoire et al. 2022; Zeder and Fischer 2024), and high temperature and windspeed lead to forest and land fires (Nugroho and Oktaviana 2023). The studies shows that disaster risk analysis using EVT can provide the information that is very useful for designing adaptation and mitigation program based on urban impacts and vulnerabilities caused by climate-related environmental disaster risk. The results like estimation of

extreme rainfall, probabilities of environmental disaster, infrastructure damage potential and the other is essential information that prove EVT is a good method for disaster risk analysis caused by climate change indicators. Applying EVT in disaster risk analysis helps to clarify the potential negative outcomes for human well-being, urban systems and infrastructure, as well as ecological environments (Hov et al. 2013). Effective disaster risk analysis requires evaluation framework in sensitivity and vulnerability test highlight the most influential factors, and climate change scenarios are then employed to provide credible boundary conditions (Brown and Wilby 2012). This information should also be accompanied by regular checks on communities directly affected by extreme events as well as those not directly involved with the rapid response team (Collings et al. 2024).

By understanding the extreme values of various natural hazards, authorities can better plan for and respond to potential disasters, allocate resources effectively, and develop strategies to reduce the impact of extreme events on communities and infrastructure. Sustained efforts in disaster preparedness and response are vital to limit the effects of natural disasters on communities and the environment (Krichen et al. 2024). By linking preparedness actions to extreme events, long term risk levels can be better anticipated (de Perez et al. 2015). Overall, disaster risk analysis using EVT provides a scientific framework for assessing and quantifying the risks associated with extreme events, thereby aiding in the development of resilient and adaptive measures to minimize the impact of disasters on society and the environment.

5. Conclusion

EVT has essential role in understanding and mitigating the risk associated with extreme climate events. Within EVT, the BM and POT methods offer complementary approaches to analysing extreme events. The BM approach, which utilizes the GEV distribution, focuses on the maximum observed values within defined time blocks, providing insight into the most extreme events over consistent intervals. Alternatively, the POT method uses the GPD to capture all instances exceeding a specified threshold, allowing for a more flexible and detailed analysis of extreme occurrences. EVT provides a powerful framework for modelling rare but catastrophic events that are expected to occur more frequently due to global warming, but attention must still be paid to the steps for selecting extreme data in EVT analysis for both BM and POT to ensure accurate analysis results.

The review underscores that while EVT offers significant predictive power, its application must be adapted to account for the evolving nature of climate extremes, particularly through non-stationary models. Future research should focus on refining non-stationary EVT models to better capture the dynamics of climate change. As climate-related disasters escalate in frequency and severity, EVT will be crucial for developing adaptive strategies that can mitigate future risks for urban impacts and vulnerabilities studies.

Author Contributions

Pratnya Paramitha Oktaviana: Writing-Original Draft, Writing-Review & Editing. Arie Dipareza Syafei: Writing-Review & Editing, Supervision. Heri Kuswanto: Writing-Review & Editing, Supervision. Joni Hermana: Conceptualization, Writing-Review & Editing, Supervision. All authors have read and agreed to the published version of the manuscript.

Ethics Statements

No ethical approval was required as this study uses published literature. AI tools were used only to assist with language translation and editing, and the authors remain fully responsible for the content.

Conflict of Interest Statement

The authors declare no conflict of interest.

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