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Analyzing Flood Return Levels Using the Gumbel Distribution in Niamey, Niger

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Abstract

Floods are among the most severe natural disasters, capable of causing significant damage to both the environment and society. This research utilizes the Gumbel distribution to analyze flood return levels by examining historical data from Niamey, Niger. The study focuses on river heights, flow rates, and precipitation patterns to understand the dynamics of flooding in the region. By analyzing these parameters, the research aims to identify severe weather trends and make predictions about future flood levels. These insights are intended to aid in disaster preparedness and the efficient management of water resources. The findings underscore the increasing frequency and severity of floods, highlighting the urgent need for enhanced infrastructure, improved data collection methods, and heightened community awareness to mitigate the adverse impacts of flooding. The project emphasizes that proactive measures are essential for minimizing the risks associated with floods. By addressing these challenges, the research hopes to contribute to the development of strategies that will better protect communities and ecosystems from the devastating effects of flooding. This comprehensive approach to flood analysis and management is crucial for building resilience against future flood events in Niamey and similar vulnerable regions.

Keywords: Flood risk, Gumbel distribution, Standardized Precipitation Index, SPI, Niamey-Niger, flood water level

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INTRODUCTION

The globe is experiencing more severe weather events such as heat waves, cyclones, droughts, and floods. These occurrences significantly influence the environment and people's livelihood, especially disadvantaged communities in the poorest areas, even though they are the least responsible for these changes. Natural catastrophes have caused considerable harm to the natural, modified, and human systems in the past. These damages tend to rise with time owing to the greater severity of the natural occurrences and the higher worth of items in danger. A recent IPCC Special Report 2021 demonstrates that human activities have caused global warming of around 1.0°C over the pre-industrial level. This is anticipated to reach 1.5°C between 2030 and 2052 if it continues to rise at the present pace. Climate change has already had numerous harmful implications on human systems, including water security, food production, health and well-being, cities, settlements, and infrastructure in the IPCC 2022 report [1–3].

Accordingly to Massazza et al. (2020), Tarchiani et al. (2021), Tiepolo, Braccio, and Fiorillo et al. (2022), floods have the greatest devastating consequences among natural catastrophes [4, 5, 6]. Floods are serious calamities affecting many nations yearly, particularly in most floodplain regions. Urban environments have been breeding grounds for catastrophes, environmental, social, economic, and human dangers and instabilities. For example, the 2011 World Urbanization Prospects indicated that roughly 890 million people were living in places with high exposure risk [7, 8].

Positive flood trends are closely associated with changes in the Sahelian rivers' flow, which numerous authors have carefully examined. Recently (Wilcox et al., 2018), We investigated the annual maximum daily flow of numerous rivers in West Africa [9]. They validated the growing trends in severe flows in the Sahelian stretch of the Niger River. They revealed the considerable non-stationarity of severe flow levels for various Sahelian tributaries during the last six decades. Non-stationary approaches in trend analysis have also been employed on the Sirba River, the principal tributary of the Middle Niger River Basin, to calculate the occurrence of flood occurrences in a setting of significantly changing river hydrology [10–12].

Niamey, the capital of Niger, is especially prone to floods as it sits on the banks of the Niger River, which in its middle basin has two flood peaks: one in summer (the red flood) and one in winter (the black flood). In 2020, the Niger River in Niamey reached its all-time greatest levels after an exceptional rainy season. On the other hand, the floods in Niamey have been prevalent in the previous decade, a sign of a shift in hydroclimatic behavior already noticed since the end of the big droughts of the 1970s and 1980s and which is recognized with the term Sahelian Paradox [11].

The repercussions in 2020 were extremely severe, and the number of persons affected quadrupled those of 2019. The most affected nations were Niger and Nigeria, with respectively more than 5 and 4 hundred thousand people affected. Floods devastated buildings, infrastructure, products, crops, and fields while worsening land degradation, erosion, and silting. Moreover, floods endanger the livelihoods of rural people, who in many of the affected areas already deal with food shortages. Floods can boost the prevalence of water-borne infections, particularly if water stagnates for weeks, as is the situation in Niamey, Niger's capital city, following the flood of early September [4].

The events of 2020 are not unique but are part of a bigger dynamic that has witnessed a substantial rise in flood occurrences and damages since the turn of the century. Massazza et al., in 2020, first pointed out that floods were becoming a serious concern for emerging Sahelian nations. During the previous 20 years, various writers observed an increasing incidence of floods and flood-related consequences in West Africa. the flood trends with a regional perspective on 11 catchments and observed a considerable rise in flood amplitude and frequency in the Sahelian area. the favorable trends in flood size and their association with the number of persons affected in the Sahelian region of the Niger River Basin. A high rise in flood episodes and accompanying damages in Niger, notably in the Tillabery, Niamey, and Dosso areas [13].

In Niger, rising flooding has been documented nationally, evaluating official data gathered by the government on damages from 1998 to 2017. Regarding the regional and sub-regional consequences of floods, the country's southwestern parts were determined to be the most susceptible to flood threats. Over the last 20 years, the scientific literature has mostly concentrated on changes in the size of floods in the Niger River, aiming to understand both the continuous changes in hydrological features and the key mechanisms prompting the increasing flooding in the area. The Niger River is just one of the drivers of flood risk in Niger, and most incidents are unrelated to river dynamics. Nowadays, floods have grown regularly accompanied by loss of lives, properties, and croplands and disrupt the livelihood of people, health, production, communication systems, and ecosystems, with substantial implications on human security. Government officials in Niamey claimed that in 2018, floods had resulted in 57 fatalities and affected 132,528 people. In late September 2019, 16,375 homes had been demolished and 211,000 individuals were implicated, in particular in the three areas of Zinder (80,534 people affected), Maradi (28,847), and Niamey (31,222) [14, 15].

Following these tragedies, different efforts at flood mapping were performed, opening the way with a flood vulnerability map that evaluated the population and the primary equipment susceptible to floods. At least three river flood event maps followed, which indicated the flooded region. Psomiadis, E., 2016 and the flood depth utilized historical data and scenarios for flood risk preliminary mapping in Niamey and didn't consider the DEM. However, none of these instruments is useful for good sustainable decision-making [5, 16, 17].

In Niger, there is a dearth of published material on flood analysis using suitable models. To address this deficiency, the present study titled "Analyzing Flood Return Levels Using the Gumbel Distribution in Niamey, Niger" aims to comprehend the repetitive nature of flood occurrences and their impact on land utilisation in Niamey. The objective is to determine the magnitude of the flood disaster in the area, and the Gumbel Distribution Method will be used to assess the occurrences of floods.

MATERIALS AND METHODS

Materials

The Study Area Description

In the center of West Africa, Niger is a landlocked Sahelian nation that spans 1267 million km2 between 11°65' and 23°55' N and 0°200' and 16°00' E. Three distinct zones can be identified within the nation: (i) the northern region, encompassing over half of the nation and primarily situated in the Sahara; (ii) central Niger, a semi-arid region within the Sahel region with an annual rainfall of 250–600 mm, primarily used for pastoral purposes; and (iii) the southern region, home to rainfed agriculture and with a mean annual rainfall that infrequently surpasses 800 mm. In the central and southern zones, the growing season lasts around three to five months, followed by a lengthy dry season that lasts seven to nine months. The predominant agricultural method is rain-fed agriculture, with millet and sorghum being the two most important grain crops. The main river that traverses the southwest is the Niger, and the periodic floods that it produces help support irrigated and recessional farming along its banks. Rain-fed agriculture and animal husbandry for sustenance are the main drivers of Niger's economy. Niamey, the capital, is situated in the southwest corner of Niamey's coordinates, which are as follows: 2°03 and 2°10 east longitude, and 13°28 to 13°35 north latitude (Figure 1). Its five communal districts are expected to have 1,324,670 residents by 2020, or an average density of 5,446 people per km^2, with an annual growth rate of 3.6% [6, 18].

The study area's primary socioeconomic activities include commerce, tourism, agriculture, cattle, fishing, and crafts. In the hydro-agricultural developments of Saga and Kirkissey, as well as along the river, rice, fruit, and market gardening are all part of irrigated agriculture. Both men and women in the community find agriculture interesting and a means of creating cash, particularly in product processing and marketing. However, the primary obstacles to agricultural output are the river's silting up, the lack of resources for pumping, and the absence of expert oversight [9].

It is situated between 180 and 250 meters above sea level on a plateau that overlooks the Niger River's left bank and an alluvial plain on its right bank. The main supply of drinking water in the city comes from this river, although there are several sanitary issues because of its ongoing deterioration brought on by pollution and desertification along its banks.

The Niger River overflow, which is affecting thousands of people in Niamey and causing periodic flooding of farmed and built-up regions, is especially problematic due to its rising levels. However, flash

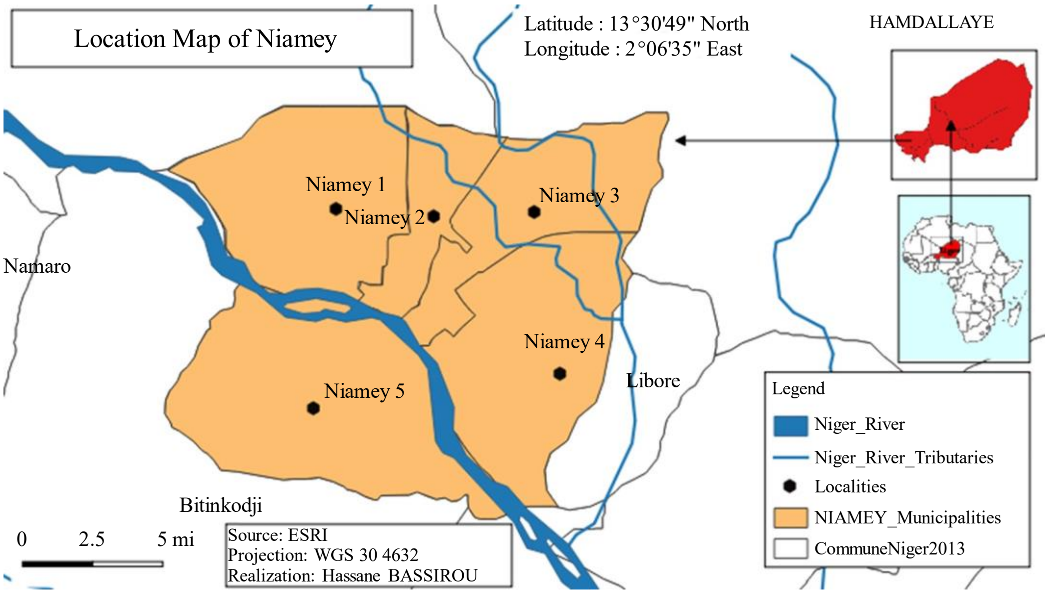

Figure 1. Location map of Niger.

floods are also a frequent occurrence in Niamey, mostly because of inadequate drainage infrastructure and poor maintenance, making river floods not the sole hydrological danger in the area (Figure 1).

Methods

Data used in this work are daily rainfall, river height, and streamflow data obtained from the Nation Direction of Meteorology Centre in Niger and the General Direction of Water Resources. The Gumbel distribution is a powerful method for extreme value analysis and can be applied in various fields to predict and understand rare but significant events. The methodological approach involves several key steps to ensure accurate and reliable analysis:

1. *Data collection and preparation*
   i. Daily data on heights, flows, and precipitation from Niamey were collected from relevant hydrological and meteorological databases.
   ii. The data spans several decades, providing a robust dataset for analysis.
   iii. Annual maxima were extracted from the daily data to fit the Gumbel distribution to the dataset. This step focuses on identifying the highest values each year to model extreme events.
2. *Data conversion*
   i. Daily data were aggregated into monthly data to calculate the Standardized Precipitation Index (SPI).
   ii. The SPI is a versatile tool that helps in identifying both drought and flood periods by standardizing precipitation levels over various timescales (e.g., 3, 6).
3. *Classification*
   i. Using the classification proposed by McKee et al. in 1993, SPI values were categorized into different anomaly classes such as near normal, moderately dry, severely wet, and so on (Table 1)
   ii. This classification aids in distinguishing between different levels of drought and wetness, providing a clear picture of climatic conditions over the study period.
4. *Statistical modelling*
   i. The Gumbel distribution, known for modelling extreme values, was fitted to the annual maxima data.
   ii. This statistical model is used to predict future flood levels and return periods based on historical extremes.
   iii. The predictions help in understanding the likelihood of extreme flood events over specified periods (e.g., 2, 10, 30, 50 years).

Table 1. Severity classification according to the standardized precipitation index (SPI).

SPI values	Fault class
More than 2.0	Extremely humid
1.5 to 1.99	Severely humid
1.0 to 1.49	Moderately humid
–0.99 to 0.99	Close to normal
–1.0 to –1.49	Moderately dry
–1.49 to –1.99	Severely dry
Less than –2.0	Extremely dry

Source: Mckee et al. (1993)

Equations/Formulas

The Gumbel distribution is defined by its cumulative distribution function (CDF):

$$F(x) = exp\left(-exp\left(\frac{x-\mu}{\beta}\right)\right) \tag{1}$$

Where, F(x) is the cumulative probability of an event x, μ is the location parameter, and β is the scale parameter

The probability density function (PDF) of the Gumbel distribution is:

$$F(x) = \frac{1}{\beta} exp\left(\frac{x-\mu}{\beta}\right) exp\left(-exp\left(\frac{x-\mu}{\beta}\right)\right) \tag{2}$$

The return period T for a given event is defined as:

$$T = \frac{1}{1-f(X)} \tag{3}$$

Rearranging the CDF formula to solve for x in terms of T:

$$X_T = \mu - \beta ln(-ln(1 - 1/T)) \tag{4}$$

Where, X_T is the value of the event corresponding to the return period T.

To estimate the parameters μ and β, the method of moments or maximum likelihood estimation (MLE) can be used. In this study, MLE is employed, with the following parameter estimates:

$$\mu = \bar{x} - \frac{\beta\sqrt{6}}{\pi} \tag{5}$$

$$\beta = \sqrt{\frac{6Var(x)}{\pi^2}} \tag{6}$$

Where, $\bar{x}$ is the sample mean, and Var(x) is the sample variance.

SPI Calculation and Analysis

Using the heights from the Comparative Analysis of Historical Flood Events, we can calculate the SPI to understand the anomaly classes and trends. The SPI values are calculated as follows:

$$SPI = \frac{X-\mu}{\sigma} \tag{7}$$

Where, X is the observed value, μ is the mean, and σ is the standard deviation.

RESULTS

Height

Return periods determined using the Gumbel distribution yielded height values of 518.66 cm, 634.08 cm, 703.55 cm, and 735.26 cm, corresponding to return periods of 2, 10, 30, and 50 years, respectively. These values indicate the expected maximum river heights for different recurrence intervals, providing crucial information for flood risk management.

Understanding these return periods is vital for assessing flood vulnerability and implementing appropriate mitigation measures. For instance, infrastructure projects such as levees, flood walls, and drainage systems can be designed to withstand the anticipated maximum heights for specific return periods, thereby reducing the impact of floods on communities and infrastructure (Figure 2).

The analysis of the SPI plot on a scale of 3 following reveals significant variations in dry and wet periods from 1990 to 2020 in Niamey. This method provides a robust framework for understanding the variability of precipitation and its impact on drought and flood occurrences over time.

From 1990 to 1994, the SPI plot indicates moderately to severely dry conditions, highlighting a prolonged dry spell during these years. This period likely posed challenges for water resources and agricultural activities in Niamey. Similarly, the years 2019 to 2020 were characterized as extremely dry, suggesting recent severe drought conditions that may have exacerbated environmental stress and water scarcity issues.

Conversely, certain periods showed notably wet conditions. For instance, from 2013 to 2018 and from 2010 to 2011, the SPI indicated severely wet conditions. These years likely experienced above-average precipitation, potentially leading to increased flood risks and challenges related to water management and infrastructure resilience (Figure 3).

Using the Gumbel distribution, return periods provided precipitation values of 61.05 mm, 90.71 mm, 108.55 mm, and 116.70 mm for return periods of 2, 10, 30, and 50 years, respectively. These values are crucial as they indicate the precipitation levels that can be expected to occur within specific recurrence intervals, providing essential information for flood risk assessment and management in Niamey.

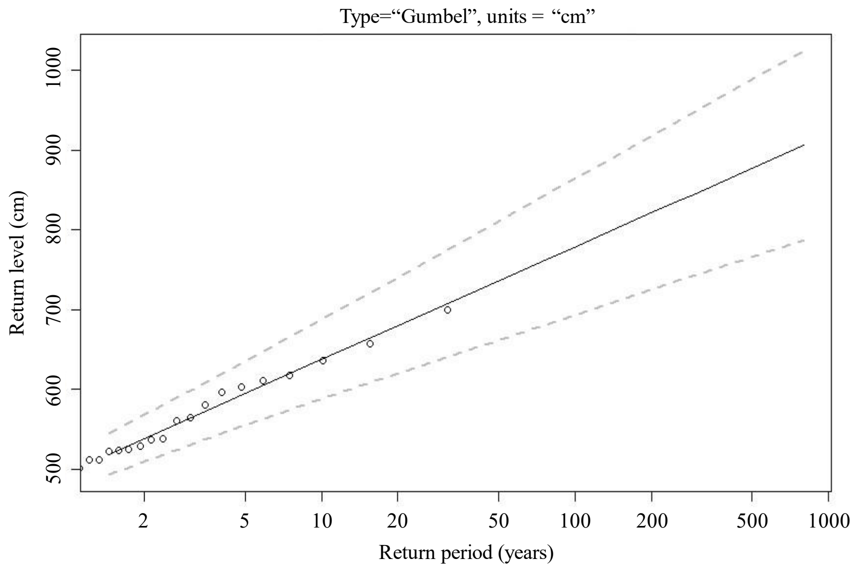

Figure 2. Return levels of heights estimated according to the Gumbel distribution over various periods.

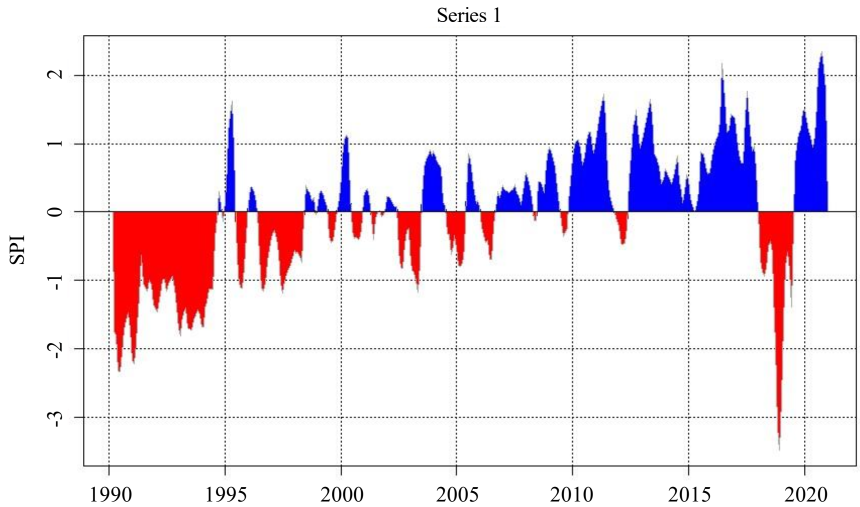

Figure 3. SPI of heights.

Understanding these precipitation values helps in assessing the likelihood and severity of floods associated with different return periods. For instance, infrastructure designs such as stormwater management systems, drainage networks, and flood barriers can be tailored to handle the expected precipitation amounts corresponding to these return periods. This proactive approach strengthens the city's resilience to extreme weather events by mitigating flood risks and minimizing potential damage to infrastructure and communities (Figure 4).

The SPI plot for precipitation on a scale of 6 highlights alternating dry and wet years. Severely dry years included 2007 and 2012, while 1992, 1997, and 2001 were moderately dry. Conversely, 1993 and 1999 were extremely wet years, and 2016, 2005, and 1995 were moderately wet.

Understanding these fluctuations in precipitation patterns is crucial for adaptive water resource management and disaster preparedness in Niamey. By identifying past dry and wet periods through SPI analysis, authorities can better anticipate future climate trends and their potential impacts. This knowledge supports the development of proactive measures such as drought-resistant agriculture, water conservation strategies, and flood control infrastructure (Figure 5).

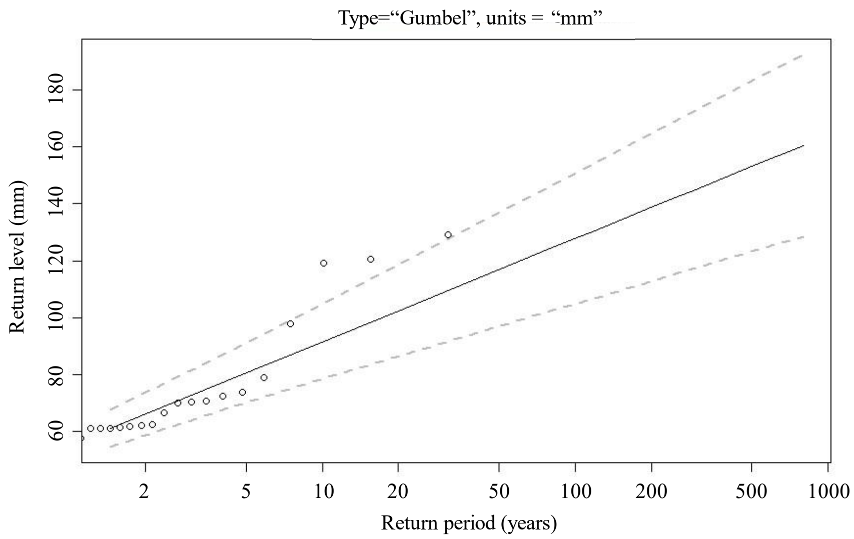

Figure 4. Return levels of precipitation estimated according to the Gumbel distribution over various periods.

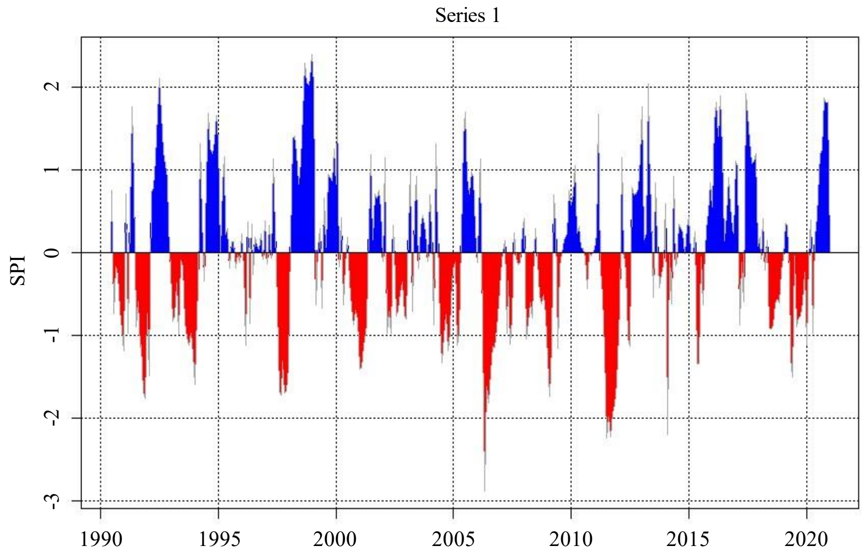

Figure 5. SPI of precipitation.

Flow

Return periods for flow values were 1722.83 m^3/s, 2305.74 m^3/s, 2656.611 m^3/s, and 2816.784 m^3/s, corresponding to return periods of 2, 10, 30, and 50 years, respectively. These flow values represent the expected river discharge levels for different return periods, which are essential for flood forecasting and water resource management.

These discharge levels are essential for assessing flood risks and designing effective flood control measures. For instance, infrastructure projects such as levees, floodwalls, and reservoirs can be planned to accommodate these expected flow rates, thereby reducing the vulnerability of communities and infrastructure to flood events.

Additionally, these values play a significant role in water resource management. They help in determining the capacity of rivers to handle water flows during different weather conditions, guiding decisions related to irrigation, hydropower generation, and ecological conservation efforts (Figure 6).

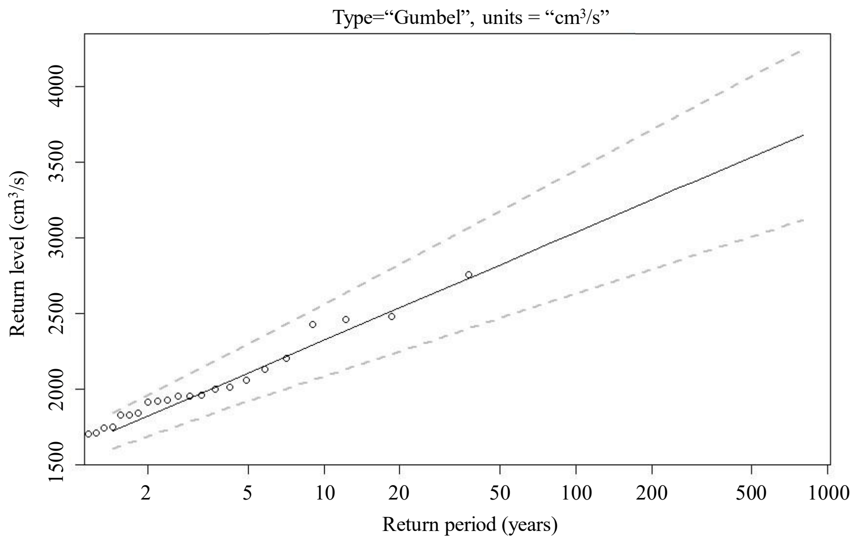

Figure 6. Return levels of flow estimated according to the Gumbel distribution over various periods.

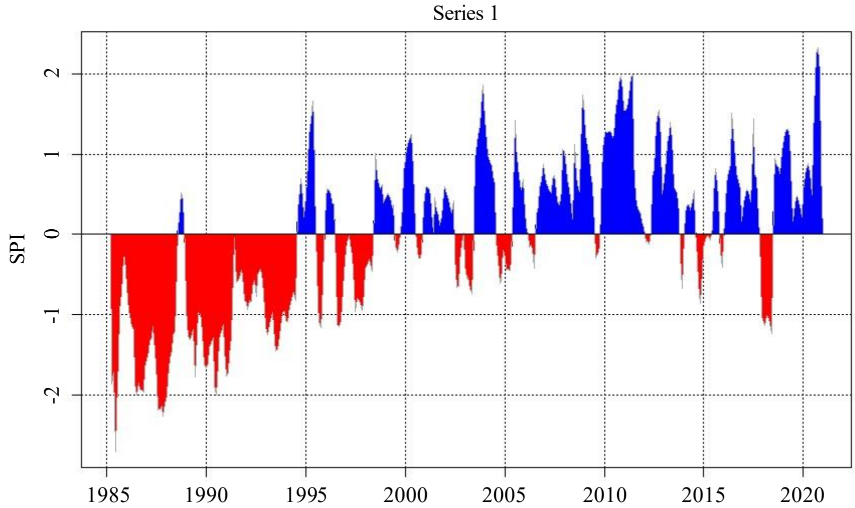

Figure 7. SPI of flow.

The SPI plot for flow on a 3-month scale indicates moderately dry years from 1985 to 1995 and a succession of moderately wet years from 1995 to 2020. During the period from 1985 to 1995, the flow rates were relatively low, consistent with the moderately dry SPI values. This indicates that there was less river flow and potentially less flooding during these years. The years 1996, 2003, and 2018 showed near-normal flow conditions, which means that the flow rates were close to the long-term average for the region. This suggests periods of stable hydrological conditions with neither extreme dry nor wet anomalies.

From 1995 to 2020, there was a noticeable shift toward wetter conditions, as indicated by moderately wet SPI values. This period saw an increase in river flow, reflecting higher precipitation rates and possibly more frequent or intense flooding events. The consistently wet conditions during this period suggest a change in the hydrological regime, possibly due to climate variability or changes in upstream land use and water management practices. The SPI analysis for flow helps in understanding these long-term trends and their implications for flood risk management (Figure 7).

DISCUSSION

The results demonstrate a strong correlation between SPI values and flood events, validating the use of the Gumbel distribution for predicting flood return levels in Niamey. Identified wet years correspond to significant flood events, while dry years align with drought periods. These findings are consistent across different data types, including water heights, river flows, and precipitation, highlighting the robustness and reliability of the methodology.

The ability to predict flood levels using historical data and statistical modeling is critical for Niamey's disaster preparedness and resource management. By understanding the return periods and associated risks, authorities can implement more effective flood control measures, improve infrastructure planning, and mitigate the impacts of extreme weather events.

Accurate flood prediction enables city planners and policymakers to prioritize investments in infrastructure that can withstand extreme weather conditions. This includes building more resilient roads, bridges, and drainage systems. Additionally, early warning systems can be enhanced to provide timely alerts to residents, reducing the potential for loss of life and property damage.

Moreover, the integration of such predictive models into broader climate adaptation strategies can support sustainable development in Niamey. It allows for the development of water management practices that can help conserve water during dry periods and efficiently manage excess water during floods. This holistic approach not only addresses immediate disaster response needs but also contributes to long-term climate resilience.

In summary, leveraging historical data and advanced statistical methods to predict flood events provides a foundation for proactive and informed decision-making. For Niamey, this means a greater ability to safeguard its population, protect economic assets, and ensure sustainable growth in the face of climate variability.

Case Studies and Applications

The Gumbel distribution has been widely applied in hydrology and environmental studies to estimate extreme events. In this study, using the Gumbel distribution for Niamey provided valuable insights into flood risks, helping local authorities design better flood management strategies. For instance, the prediction of extreme river heights can inform the construction of levees and flood barriers, while anticipated flow rates can guide the management of dams and reservoirs.

Limitations

While the Gumbel distribution is effective for modeling extreme values, it is important to acknowledge its limitations. The model assumes that the data follows a specific distribution pattern, which may not always be the case in real-world scenarios. Additionally, the accuracy of the predictions heavily depends on the quality and length of the historical data used.

CONCLUSION

This study successfully applied the Gumbel distribution to analyze flood return levels using historical hydrological data from Niamey, Niger. The methodology not only provided reliable predictions of flood levels but also identified critical periods of extreme weather, demonstrating its effectiveness in water resource management and disaster preparedness. These findings offer valuable insights for both future research and practical applications in flood risk assessment.

The study highlights the importance of statistical modeling in understanding and mitigating flood risks. By accurately predicting flood levels, authorities can better prepare for and respond to potential disasters, ultimately saving lives and minimizing economic losses. The emphasis on continuous monitoring and data collection is crucial for refining predictive models and improving their accuracy over time. This iterative process allows for adjustments based on real-world observations and ensures that flood management strategies remain effective and adaptive.

Looking ahead, future studies could benefit from incorporating additional variables into their models, such as changes in land use and climate projections. These factors can significantly influence flood dynamics and should be integrated to enhance the comprehensiveness of flood prediction models. Exploring alternative statistical distributions beyond the Gumbel distribution could also provide further insights and potentially improve the robustness of flood forecasting methods.

Indeed, applying statistical modeling, particularly the Gumbel distribution, in analyzing flood return levels represents a significant advancement in flood risk assessment for Niamey. Continued research and innovation in this field will be pivotal in advancing our understanding of flood dynamics and enhancing resilience to extreme weather events in the region.

Recommendations

1. *Enhanced data collection:* Continuous and high-quality data collection is crucial. Implementing automated hydrological and meteorological stations across Niamey and the Niger River basin can ensure real-time data acquisition, improving the accuracy of predictive models.

2. *Integrated water resource management:* Adopt *integrated water resource management* practices to balance the needs of various stakeholders, including agriculture, urban development, and environmental conservation. This approach can mitigate the impacts of extreme weather events by promoting sustainable water use and conservation.
3. *Infrastructure development:* Based on the predicted return levels, strengthen flood defence infrastructure, including levees, flood walls, and drainage systems. Prioritize areas identified as high-risk to protect communities and critical infrastructure.
4. *Community awareness and preparedness:* Educate communities about flood risks and emergency preparedness. Implement early warning systems that leverage the predictive capabilities of the Gumbel distribution to provide timely alerts and evacuation plans.
5. *Policy and planning:* Integrate the findings of this study into urban planning and development policies. Ensure that new constructions and urban expansions consider flood risks, incorporating flood-resilient designs and land-use planning.
6. *Further research:* Encourage further research to refine and validate the use of the Gumbel distribution and other statistical models in different hydrological contexts. Explore the impact of climate change on flood patterns to develop adaptive strategies.
7. *Regional collaboration:* Foster regional collaboration among countries within the Niger River basin. Sharing data and resources can enhance collective understanding and management of flood risks, benefiting all riparian nations.

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Data Availability Statement
Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request and on the Digital Earth Africa platform.

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Conflicts of Interest
The authors declare no conflict of interest.

REFERENCES

1. Adawiyah CW, Abdullah L. FSAW for REIT selection in multi-criteria decision making. In: AIP Conf Proc. 2014; 1605 (February): 1098–1104. Doi: 10.1063/1.4887744. Melaka, Malaysia: AIP.
2. Aich V. Floods in the Niger River Basin in the face of global change: analysis, attribution and projections. 2015 [dissertation]. Potsdam, Germany: University of Potsdam; 2015. [Online] Available at https://publishup.uni-potsdam.de/frontdoor/index/index/docId/9157
3. Bassirou H, Gnazou MD, Ibrah SS, Cheo AE. Mapping flood risk using Sentinel-1 data: A case study of Niamey, Niger. Int J Environ Stud. 2022; 8 (2): 14–26.

4. Massazza G, Tarchiani V, Andersson JCM, Ali A, Ibrahim MH, Pezzoli A, et al. Downscaling regional hydrological forecast for operational use in local early warning: HYPE models in the Sirba River. Int J Dis Risk Red. 2020; 6 (3).
5. Tarchiani V, Fiorillo E, Lawan KG, Tiepolo M. Les inondations au Niger 1998-2020. Int J Environ Stud. 2021. Doi: 10.13140/RG.2.2.33927.52645.
6. Tiepolo M, Braccio S, Fiorillo E, Galligari A, Lawan G, Massazza G, et al. Participatory risk assessment of pluvial floods in four towns of Niger. Int J Dis Risk Red. 2022; 84 (November): 103454. Doi: 10.1016/j.ijdrr.2022.103454.
7. Bassirou H, Gnazou MD, Sanda IS, Cheo AE, Sougué M, Ibrahim P. Extreme rainfall and streamflow in Niamey City: Trends and relationship between higher streamflow and rainfall. Int J Environ Stud. 2023; 9 (1): 21–32.
8. Descroix L, Mahé G, Lebel T, Favreau G, Galle S, Gautier E, et al. Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: A synthesis. J Hydrol. 2009; 375 (1–2): 90–102. Doi: 10.1016/j.jhydrol.2008.12.012.
9. Wilcox C, Vischel T, Panthou G, Bodian A, Blanchet J, Descroix L, et al. Trends in hydrological extremes in the Senegal and Niger Rivers. J Hydrol. 2018; 566 (July): 531–545. Doi: 10.1016/j.jhydrol.2018.07.063.
10. Field CB, Barros VR, Mach K, Mastrandrea MD, van Aalst M, Adger WN, et al. IPCC 2014 impacts—technical summary. In: Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press; 2014. 1–29 p.
11. Fiorillo E, Crisci A, Issa H, Maracchi G, Morabito M, Tarchiani V. Recent changes of floods and related impacts in Niger based on the ANADIA Niger flood database. Climate. 2018; 6 (3): 1–13. Doi: 10.3390/cli6030059.
12. Garba I, Abdourahamane ZS. Extreme rainfall characterisation under climate change and rapid population growth in the city of Niamey, Niger. Heliyon. 2023; 9 (2) . Doi: 10.1016/j.heliyon.2023.e13326.
13. Massazza G, Tarchiani V, Ibrahim MH, Terenziani A. SLAPIS: Evaluation année hydrologique 2020 et améliorations 2021. Int J Environ Stud. 2021; April. Doi: 10.13140/RG.2.2.35054.95041.
14. OCHA. (2020). Niger flooding causes over 36,000 houses to collapse. [Online] Available at https://reliefweb.int/report/niger/niger-flooding-causes-over-36000-houses-collapse
15. Pörtner H, Roberts D, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, et al. Climate change 2022: Impacts, adaptation and vulnerability working group II contribution to the IPCC sixth assessment report. Cambridge, England, UK: Cambridge University Press; 2022. Doi: 10.1017/9781009325844.
16. Sighomnou D, Descroix L, Genthon P, Mahé G, Moussa IB, Gautier E, et al. La crue de 2012 à Niamey: Un paroxysme du paradoxe du Sahel? [The Niger River Niamey flood of 2012: the paroxysm of the Sahelian paradox?]. Secheresse. 2013; 24 (1): 3–13. Doi: 10.1684/sec.2013.0370.
17. Tiepolo M, Braccio S. Flood risk preliminary mapping in Niamey, Niger. In: Planning to cope with tropical and subtropical climate change. Berlin, Germany: De Gruyter; 2016. 201–220 p. Doi: 10.1515/9783110480795-013.
18. UNISDR. (2009). UNISDR terminology on disaster risk reduction. [Online] Available at https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction

