



## Flood Modeling in Boma: Relationships between Congo River Water Height, Kalamu River Flow and Social Risks

[Modélisation des Inondations à Boma: Relations entre Hauteur d'Eau du fleuve Congo, Débit de Rivière Kalamu et Risques Sociaux]

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### Résumé

Les inondations urbaines à Boma, en République Démocratique du Congo, représentent un enjeu majeur dans le contexte actuel de changement climatique, où la fréquence et l'intensité des événements extrêmes augmentent. Cette étude se concentre sur l'analyse des relations entre la hauteur d'eau du fleuve Congo, le débit de la rivière Kalamu et les risques d'inondation qui affectent la population locale. Les objectifs principaux de cette recherche sont de modéliser le débit de la rivière Kalamu en fonction de la hauteur d'eau du fleuve Congo et d'explorer la relation entre ces variables et le nombre de décès dus aux inondations au cours de la période de 1985 à 2022. Pour atteindre ces objectifs, une approche méthodologique mixte a été adoptée. Des données hydrologiques historiques ont été collectées auprès de l'agence météorologique et de la Congolaise des Voies Maritimes, tandis que des analyses quantitatives et qualitatives ont été effectuées pour évaluer les impacts des inondations. Des modèles statistiques, tels que la régression linéaire, ont été utilisés pour établir les relations entre les variables étudiées. Les résultats révèlent une corrélation significative entre la hauteur d'eau du fleuve et le débit de la rivière, ainsi qu'un lien direct avec le nombre de décès lors des inondations. Ces découvertes soulignent l'importance de surveiller les niveaux d'eau et d'améliorer les infrastructures de drainage pour atténuer les risques d'inondation à Boma. Enfin, il serait mieux de mettre en place des systèmes d'alerte précoce et de sensibiliser les communautés aux risques liés aux inondations.

**Mots-clés :** Inondation, Boma, Hauteur d'eau du fleuve Congo, Débits de rivière Kalamu, Changement climatique.

### Abstract

Urban flooding in Boma, Democratic Republic of Congo, represents a major challenge in the current climate change context, where the frequency and intensity of extreme events are increasing. This study focuses on analyzing the relationships between the Congo River water level, the Kalamu River discharge, and flood risks affecting the local population. The main objectives of this research are to model the Kalamu River discharge as a function of the Congo River water level and to explore the relationship between these variables and the number of flood-related deaths during the period 1985 to 2022. To achieve these objectives, a mixed methodological approach was adopted. Historical hydrological data were collected from the meteorological agency and the Congolaise des Voies Maritimes, while quantitative and qualitative analyses were conducted to assess the impacts of flooding. Statistical models, such as linear regression, were used to establish the relationships between the variables studied. The results reveal a significant correlation between river water level and river discharge, as well as a direct link with the number of deaths during floods. These findings highlight the importance of monitoring water levels and improving drainage infrastructure to mitigate flood risks in Boma. Finally, it will be better to implement early warning systems and raise community awareness of flood risks.

**Keywords:** Flood, Boma, Congo River water level, Kalamu River discharge, climate change.

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## 1. Introduction

Urban flooding represents a major issue in the current context of climate change, where the frequency and intensity of extreme events are increasing. Recent research, such as that of [Guelbeogo et al. \(2023\)](#), highlights that flood forecasting and water resource management are critical challenges. Furthermore, inadequate drainage infrastructure increases the vulnerability of urban areas during rainfall events. These challenges require an integrated approach to flood management, including infrastructure rehabilitation and land-use planning.

The city of Boma, located in the Kongo Central province of the Democratic Republic of Congo, regularly faces devastating floods. These events are exacerbated by a combination of climatic factors, such as extreme rainfall, and anthropogenic factors, including rapid urbanization and the overflow of the Congo and Kalamu Rivers. Analyzing flooding in Boma is essential for understanding the consequences for the population, habitat, and ecosystem.

The importance of flooding in Boma is also highlighted by several previous studies. For example, [Lavabre et al. \(2003\)](#) developed methods to estimate flood flows, which is relevant for understanding the hydrological dynamics of the region. [Abderraouf Benaoudj et al. \(2014\)](#) examined flooding in the M'zab Valley, highlighting the importance of environmental factors and the need for adaptation strategies. [Furusho et al. \(2015\)](#) discussed collaboration between scientific and operational stakeholders to improve flood forecasting systems, a key aspect for Boma. [Chen et al. \(2013\)](#) explored network flow simulations, providing tools that could be applied to water management in Boma. [Koungbanane et al. \(2020\)](#) conducted a frequency analysis of flood risks, which could inform forecasts for the region. [Breil \(2018\)](#) discussed the importance of wetlands for flood prevention, a crucial consideration for land use planning in Boma. Other studies, such as [Lang et al. \(2022\)](#), have assessed uncertainties in flood flow series, providing insights into climate variability. [Foën \(2005\)](#) analyzed past flood events, which can serve as a benchmark for understanding trends in Boma. [Douvinet et al. \(2011\)](#) examined the challenges local authorities face in flood prevention, highlighting the importance of appropriate public policies. [Cafarelli \(2023\)](#) highlighted the resilience of territories exposed to natural hazards, which is relevant for management strategies in Boma. [Rode et al. \(2022\)](#) addressed territorial adaptation to

flood risk, a necessary aspect for the rapid urbanization of Boma. [Derdour et al. \(2017\)](#) studied flood typologies in semi-arid environments, shedding light on flood mechanisms. [Ibouraïma et al. \(2019\)](#) discussed climate change and its impact on flooding, which is crucial in the current context. Sene and [Ozer \(2002\)](#) studied rainfall trends and their relationship with flooding, providing useful historical data. Finally, [Rey et al. \(2018\)](#) proposed nature-based solutions for flood management, an innovative approach that could be applied in Boma.

Despite the importance of flooding in Boma, there are gaps in understanding the interactions between different hydrological variables. Few studies have focused on the specific dynamics of flooding in Boma, creating an opportunity for targeted research. In particular, the impact of urbanization on flooding has not been adequately studied, despite being crucial in the context of a rapidly growing city.

From 1985 to 2022, the city of Boma recorded 51 flood-related deaths, illustrating the urgent need for a thorough analysis of contributing factors. The current research seeks to address the gaps identified in the state of the art by conducting a detailed examination of the relationship between the Congo River water level, the Kalamu River discharge, and the number of flood-related deaths. The main objective of this research is to analyze the drivers and consequences of flooding in Boma. More specifically, the study proposes to model the Kalamu River discharge in relation to the Congo River water level and to examine the relationship between these variables and the number of deaths recorded during the period 1985 to 2022. This analysis aims to provide recommendations for effective flood risk management. To achieve these objectives, a mixed methodological approach will be employed. Quantitative analyses of hydrological data, including water levels and discharges, will be combined with qualitative studies on the social impacts of flooding. Historical data were collected from the meteorological agency, the Congolese Maritime Authority, and flood-related documentation. Statistical models, such as linear regression, will be used to establish relationships between the variables studied. This analytical framework aims to shed light on contemporary flooding issues in Boma and to propose recommendations for proactive risk management.

## 2. Material and Methods

### 2.1 Presentation of the study environment

The study was conducted in the town of Boma, as well as in the Kalamu River watershed, along the Kalamu River, as shown in figures 1 and 2. Before flowing into the Congo River near the port of Boma, the Kalamu River flows through three communes of the town: Kabondo, Nzadi, and Kalamu (Vuni et al., 2020). The Kalamu River watershed covers an area of 68.84 km<sup>2</sup> and a perimeter of 44.36 km.

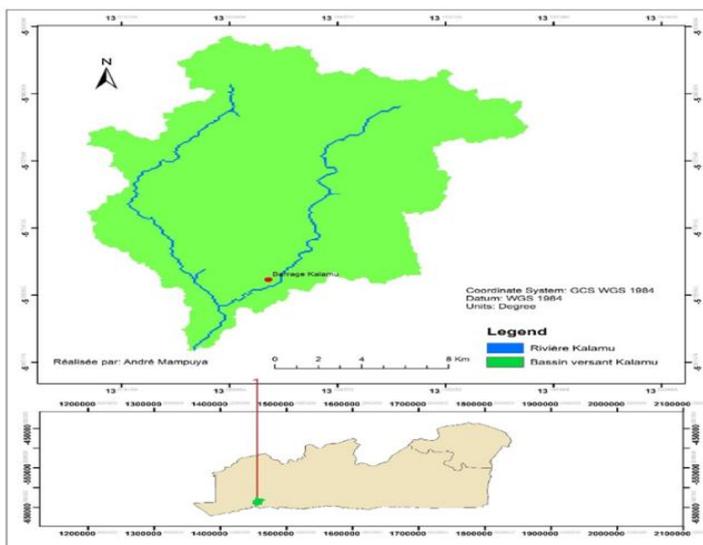


Figure 1. Kalamu River watershed at Boma

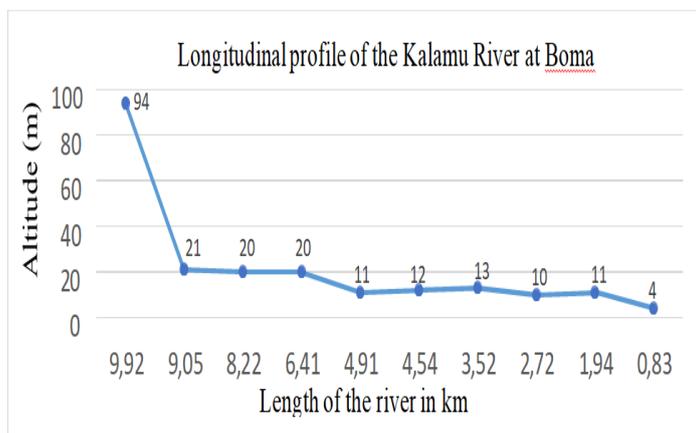


Figure 2. Length of the Kalamu River

### 2.2 Data collection

Crucial data were collected from various sources in table I. The water level of the Congo River was recorded by the Congolese Maritime Authority called ‘Compagnie des Voies Maritimes’ (CVM) in Boma, covering the period from 1960 to 2017. Monthly precipitation and evaporation data were obtained from

the Boma meteorological station, covering the period from 1992 to 2023. Historical information on Kalamu River flows and the number of deaths in years corresponding to floods was provided by flood-related documentation in Boma (Vuni et al., 2020).

Table I illustrates the data for the flood study variables.

Table I. Variables associated with flooding in Boma by year

Year of floods	Water level of the Congo River (m)	Congo River flood	Flow rate of the Kalamu River on flood day (m <sup>3</sup> /s)	Number of deaths from flooding	Flood day precipitation (mm)
23/12/1985	2.6	Large	20.53	3	207.9
12/12/1999	3.39	Large	36.32	0	365.8
30/12/2000	2.83	Large	25.85	0	260.6
20/12/2010	2.79	Large	24.97	0	252.1
12/12/2015	3.31	Large	24.51	4	247.1
26/12/2016	3.5	Large	47.62	40	458.6
05/12/2018	3.01	Large	15.53	0	158.1
26/11/2019	3.24	Large	12.71	2	129.7
03/11/2021	2.93	Large	23.84	2	240.9
03/12/2022	2.74	Large	23.76	0	240

### 2.3. Anaconda Python tools and software for modeling Kalamu River flow as a of Congo River water level and analyzing associated deaths

Data analysis began with the import of essential libraries such as Pandas, NumPy, Matplotlib, Seaborn, and Scikit-learn for data manipulation and visualization (Pierrefeu et al., 2022). The Congo River discharge data were converted into a DataFrame, with a transformation of the “Year” column to datetime format to ensure consistency (Laraque et al., 2022). For regression analysis, the independent variables X were defined as a time sequence, while Y represented the discharges. A linear regression model was created and trained with Scikit-learn. Model evaluation extracted the intercept and slope, and Student t-tests and Pearson correlation tests were performed to verify the statistical significance of the coefficients (Magrin & Mugel , 2020; Mampuya et al., 2024; Nzita et al., 2024).

The results were visualized from a linear regression model between the flow rate of the Kalamu River at Boma versus the water level of the Congo River and the number of deaths related to flooding with the visualization of this correlation of three parameters, visualizing correlation and p-value matrices (Ago et al., 2005; Kayser et al., 2019).

### 3. Results

#### 3.1. Analysis of the flooding related to the Kalamu River

Figure 3 illustrates the relationship between subsequent rainfall in the study years and death counts versus the length of the Kalamu River using the Python Anaconda software for visualization.

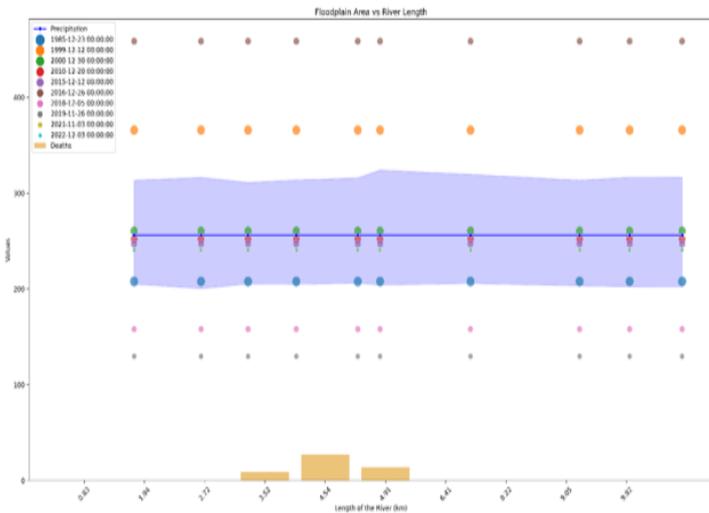


Figure 3. Analysis of flooding related to the Kalamu River: Relationship between rainfall, river length and number of deaths

To analyze the flooding related to the Kalamu River, we will look at several aspects, including dates, rainfall, river length, and the number of deaths in figure 3. First, rainfall is represented by color shades in the figure. The blue shade indicates areas of rainfall, with each shade corresponding to a specific year. In 2016, the chocolate-colored shade signifies particularly high rainfall, reaching 458.6 mm, which led to a significant number of deaths, namely 40. This year is followed by 1999, represented in orange, with a rainfall of 365.8 mm, but no recorded deaths. In 2000, the green color represents a rainfall of 260.6 mm, also with no deaths. At the other end, the gray color of 2019 indicates the lowest rainfall of 129.7 mm, with only 2 deaths. Regarding the length of the Kalamu River, which ranges from 2.72 km to 6.41 km, deaths are concentrated in this area. In Boma, it is noted that 9 deaths occurred at the 3.52 km point (elevation 13 m), 27 deaths at 4.54 km (elevation 12 m), and 14 deaths at 4.91 km (elevation 11 m). These points show a correlation between elevation and recorded deaths, suggesting that lower areas closer to the river are more vulnerable to flooding. The color hues in the figure also provide clues to the impacts of flooding. Blue areas indicate periods of heavy rainfall, while gray indicates periods of drought, which are often associated with

fewer deaths. The most frequent deaths are observed in areas with high rainfall, confirming the direct impact of weather conditions on population safety.

#### 3.2. Analysis of the flooding and their consequences in the town of Boma

This analysis highlights the importance of rainfall in the severity of floods and their tragic consequences for the population while revealing the most affected areas along the Kalamu River. The data highlight a relationship between rainfall levels, river length, and the number of deaths, which is crucial for planning future interventions. table II presents the Student t-test of the variables related to flooding in Boma.

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Table II. Student t-test of the variables related to flooding

Variables	Mean	Standard deviation	df	t	p-value
Congo River Water Level	3,034	0,307	9	31,223	$2 \times 10^{-11}$
Kalamu River Flow	25,564	10,007	9	8,079	$2.05 \times 10^{-5}$
Deaths	5,100	12,351	9	1,306	0,224
Precipitation	256,080	95,191	9	8,507	$1.35 \times 10^{-5}$

Table III. Correlation matrix of variables related to flooding in Boma

Correlation Matrix	Congo River Water Level	Kalamu River Flow	Deaths	Precipitation
Congo River Water Level	1	0.519	0.546	0.511
Kalamu River Flow	0.519	1	0.749	0.999
Deaths	0.546	0.749	1	0.722
Precipitation	0.511	0.999	0.722	1

Table IV. P-value matrix of variables related to flooding in Boma

P-Value Matrix:	Congo River Water Level	Kalamu River Flow	Deaths	Precipitation
Congo River Water Level	0.000	0.123	0.103	0.131
Kalamu River Flow	0.123	0.000	0.013	$2.45 \times 10^{-12}$
Deaths	0.103	0.013	0.000	0.018
Precipitation	0.131	$2.45 \times 10^{-12}$	0.018	0.000

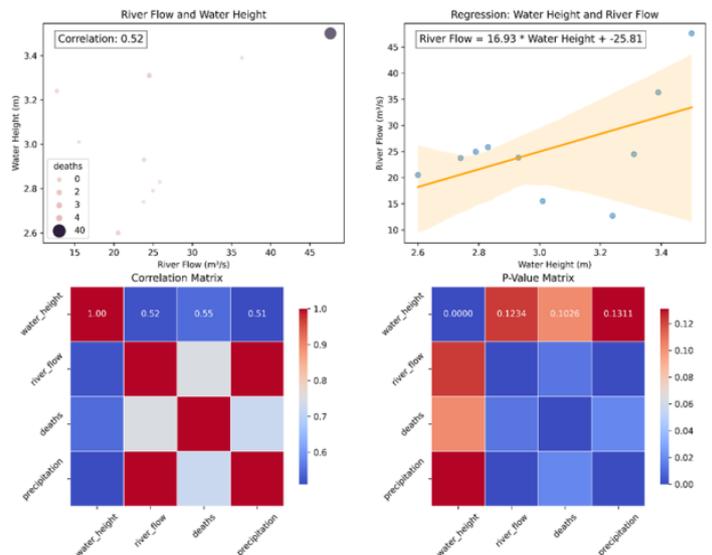
In [table III](#), the analysis of flooding in the town of Boma, at the outlet of the Kalamu River, is based on several interconnected factors, which we will explore using the provided correlation data. First, the water level of the Congo River at the outlet plays a crucial role. It shows a significant correlation with several other variables. Indeed, as the water level increases, we observe a positive relationship with the flow of the Kalamu River (0.52) as well as with the number of flood-related deaths (0.55). This means that higher water levels in the Congo River are often associated with higher flows in the Kalamu River, which can exacerbate flood risks and, consequently, increase the number of victims. In addition, the water level of the Congo River is also correlated with precipitation (0.51). This relationship suggests that an increase in precipitation can lead to a rise in the water level in the river, thus amplifying flood risks. The interaction between rainfall and water level is therefore a key factor to monitor. Regarding the Kalamu River's flow, it shows a strong correlation with deaths (0.75) and an almost perfect correlation with precipitation (0.99). This indicates that higher river flows, often caused by intense rainfall, also increase the number of flood-related deaths. Water management in this region must therefore take these dynamics into account to minimize human losses.

The p-values confirm the significance of these correlations. For example, the p-value for the correlation between river flow and deaths is very low ( $2.45 \times 10^{-12}$ ), indicating a high probability that this relationship is significant and not a coincidence in [table IV](#). The very low p-values for the correlations between flow and precipitation, as well as the Congo River's water level, indicate that these relationships are significant. This means that increases in rainfall and flow have direct implications for flood levels.

This analysis shows that the water level of the Congo River, the flow rate of the Kalamu River, rainfall, and the number of deaths are interconnected. For effective flood management in Boma, it is crucial to monitor these factors and adapt prevention strategies based on the data collected.

The modeling of the linear regression equation of the flow of the Kalamu River at Boma in relation to the water level of the Congo River and the number of deaths related to flooding is written in the form ([figure 4](#)):

$$\text{River Flow} = 16.93 \times \text{Water Height} - 25.81 \quad (1)$$



**Figure 4.** Linear regression modeling of Kalamu River discharge versus Congo River water level and analysis of flood-related deaths

To analyze flooding in the town of Boma in [figure 4](#), which shows the relationship between the Congo River water level and the Kalamu River discharge, several key points can be interpreted. Using the correlation matrix and the p-value matrix, this provides essential information on the relationships between various flood-related factors. [tables III](#) and [IV](#) are detailed. First, the correlation of 0.52 between the Congo River water level and the Kalamu River discharge indicates a moderately positive relationship. This means that as the river water level increases, the Kalamu River discharge tends to increase as well. This dynamic is crucial because it implies that higher water levels in the river can contribute to higher river flows, which increases the risk of flooding in the surrounding areas.

Next, examining the scatter plot in the regression graph, we observe that river discharge values increase with water level. The regression line, described by the equation  $\text{River Flow} = 16.93 * \text{Water Height} - 25.81$ , shows that for every one-meter increase in water depth, river discharge increases predictably. This underscores the linear nature of the relationship, which can facilitate predictions regarding flow based on changes in water depth. Furthermore, it is important to pay attention to the data points near the upper boundary of the graph, where fatalities are noted. These points indicate that at high water depths, the risk of death increases significantly. This reinforces the idea that proactive

water level management is essential to prevent tragedies. Finally, the correlation matrix in the bottom right corner of the figure also allows us to observe the relationships between several variables.

The correlation between water depth and flow, along with other factors, can provide valuable insights for flood management. This analysis highlights the importance of monitoring the water level of the Congo River, as it directly influences the flow of the Kalamu River. To effectively manage flood risks in Boma, it is essential to monitor these dynamics and adopt appropriate prevention strategies.

## 4. Discussion

### 4.1 Analysis of the flooding related to the Kalamu River

A study of flood modeling in Boma: Relationships between the water height of the Congo River, the flow of the Kalamu River, and social risks confirms several studies.

To analyze flooding related to the Kalamu River, several aspects were examined, including dates, rainfall, and the number of deaths. The data show that rainfall, represented by colors in [figure 3](#), reveals significant variations from one year to the next. In 2016, rainfall reached 458.6 mm, resulting in 40 deaths, highlighting the direct impact of extreme rainfall events. In contrast, the year 1999, with 365.8 mm of rainfall, did not record any deaths, indicating that other factors may also influence mortality during floods. These results confirm the findings of [Guelbeogo et al. \(2023\)](#), who emphasize the importance of analyzing the interactions between rainfall and population vulnerability. Previous work by [Breil \(2018\)](#) also supports the idea that inadequate drainage infrastructure exacerbates the effects of heavy rainfall, which could explain the disparity in observed deaths. Regarding the length of the Kalamu River, deaths are concentrated in the lowest areas, with 9 deaths at 3.52 km, 27 deaths at 4.54 km, and 14 deaths at 4.91 km.

### 4.2. Analysis of the flooding and their consequences in the town of Boma

This correlation between altitude and deaths suggests that areas closer to the river are more vulnerable to flooding. This is consistent with the work of [Abderraouf et al. \(2014\)](#), who showed that topography plays a crucial role in the impact of flooding. The water height of the Congo River has a mean of 3.034 meters with a standard deviation of 0.307. The high t-statistic of 31.223 and the very low p-value ( $2 \times 10^{-11}$ ) show that this mean is statistically significant. This indicates that variations in water depth

have a direct impact on flood conditions. These results corroborate the work of [Guelbeogo et al. \(2023\)](#), which highlights the importance of water depth in flood forecasting. The Kalamu River discharge has a mean of 25.564 m<sup>3</sup>/s and a standard deviation of 10.007. The t-statistic of 8.079 and the p-value of  $2.05 \times 10^{-5}$  also indicate that this mean is significant, suggesting that fluctuations in flow contribute to flooding. On the other hand, some studies, such as those of [Lavabre et al. \(2003\)](#), show that other factors, such as urbanization, can influence flow, highlighting the complexity of the interactions. Regarding the number of deaths, the mean is 5.100 with a standard deviation of 12.351. The t-statistic of 1.306 and the p-value of 0.224 indicate that this mean is not significant. This may mean that deaths are not directly related to variations in water height or flow. Previous research ([Abderraouf et al., 2014](#)) suggests that socioeconomic factors may also play a role, which complicates the analysis of flood-related deaths. Rainfall has a mean of 256.080 mm and a standard deviation of 95.191. The t-statistic of 8.507 and the p-value of  $1.35 \times 10^{-5}$  confirm that precipitation plays a crucial role in flooding, with intense rains leading to a rapid rise in water levels. These observations are consistent with the findings of [Koungbanane et al. \(2020\)](#), who identify rainfall as a key factor contributing to flood risk. Urbanization in Boma town reduces the river's capacity to manage floods, increasing the vulnerability of residents.

This illustrates how land use affects flood risk, a conclusion also supported by [Furusho et al. \(2015\)](#). The analysis reveals a significant positive correlation of 0.52 between the Congo River water level and the Kalamu River discharge. This means that an increase in water level generally leads to an increase in discharge, thus exacerbating flood risk. These results are consistent with the findings of [Guelbeogo et al. \(2023\)](#), who showed that high water levels in rivers are often associated with increased discharges in tributary rivers. The correlation between river water level and the number of flood-related deaths is 0.55. This indicates that higher water levels are often associated with an increased number of deaths, highlighting the severity of flooding. [Abderraouf et al. \(2014\)](#) also observed that higher water levels increase population vulnerability, reinforcing the relevance of this correlation. The Kalamu River discharge has a strong correlation of 0.75 with the number of deaths. This suggests that higher flows, often caused by intense rainfall, increase the number of deaths due to flooding. The work of [Chen et al. \(2013\)](#) corroborates this

observation, highlighting that high flows can lead to fatal flood conditions. The correlation between river height and rainfall is 0.51.

This indicates that increased rainfall can lead to a rise in water level, thus amplifying flood risk. However, previous research [Koungbanane et al. \(2020\)](#) shows that the effects of rainfall can be mitigated by factors such as stormwater management and drainage infrastructure. This equation indicates that for every one-meter increase in water depth, river discharge increases predictably. The correlation of 0.52 between water depth and discharge highlights a moderately positive relationship. These results are consistent with studies by [Guelbeogo et al. \(2023\)](#), which show that high water levels in rivers are often associated with increased flows in tributary rivers. The correlation between Kalamu River discharge and the number of deaths is 0.75.

This suggests that higher flows, often caused by intense rainfall conditions, increase the risk of death during floods. The work of [Chen et al. \(2013\)](#) supports this observation, indicating that high flows are often associated with loss of life during floods. The correlation between Congo River water depth and the number of deaths is 0.55. This indicates that a rise in river water level is generally associated with an increase in the number of deaths, highlighting the importance of monitoring these levels to anticipate flood risks. However, previous studies, such as those of [Abderraouf et al. \(2014\)](#), show that other socioeconomic factors can also influence mortality during floods. Rainfall has a positive correlation of 0.51 with river water height. This means that heavier rainfall generally leads to a rise in water levels, which can contribute to flooding. [Koungbanane et al. \(2020\)](#) corroborate this relationship, indicating that rainfall is a key factor in increasing water levels. This study makes significant contributions to the understanding of flood dynamics in Boma. First, it highlights the complex relationships that exist between rainfall, the water level of the Congo River, the flow of the Kalamu River, and the vulnerability of local populations. By analyzing these interactions, the study helps identify the key determinants that influence flooding, thus providing valuable insights to guide risk management efforts. Furthermore, the results obtained provide a solid basis for the development of flood adaptation and prevention strategies. By better understanding the factors that contribute to flooding, authorities and

decision-makers can develop more effective action plans. In light of the findings of this study, it is crucial to invest in improving drainage infrastructure.

This includes the establishment of adequate drainage systems, particularly in highly vulnerable areas, to reduce flood risks. At the same time, it is necessary to integrate land-use considerations into urban planning. This could involve efforts to limit urbanization in at-risk areas, thereby helping to mitigate the impact of flooding on communities. Furthermore, the establishment of early warning systems is essential. By developing meteorological and hydrological monitoring systems, authorities could anticipate extreme weather events and inform at-risk populations, giving them the opportunity to take preventive measures. It is also important to raise community awareness of flood risks. Through educational programs, residents can be informed of precautionary measures to protect their safety. Finally, promoting a collaborative approach between local authorities, scientists, and communities is essential. Such collaboration would facilitate integrated water resources and flood management, thus enhancing the effectiveness of interventions.

The recommendations emerging from this study are supported by various previous studies. For example, research by [Guelbeogo et al. \(2023\)](#) highlights the importance of early warning systems for flood management. Similarly, [Lavabre et al. \(2003\)](#) emphasize the need for effective drainage infrastructure to minimize the impacts of flooding. [Abderraouf et al. \(2014\)](#) also confirm that urban planning that integrates environmental considerations is crucial to reduce population vulnerability.

## 5. Conclusion

This study shed light on the complex dynamics of flooding in Boma, Democratic Republic of Congo, by analyzing the relationships between the water level of the Congo River, the flow rate of the Kalamu River, and the associated risks to the local population. The results indicate a significant correlation between these variables, highlighting that higher water levels lead to increased flows in the river, which increases the risk of flooding and, consequently, the number of deaths. This underscores the importance of continuous monitoring of water levels and improving drainage infrastructure to mitigate the impacts of flooding. The implications of this research are broad.

Local authorities and decision-makers can use this information to develop flood risk management strategies, including the establishment of early warning systems and community awareness programs. Furthermore, integrating environmental considerations into land use planning is crucial to reduce the vulnerability of urban areas. Furthermore, this study paves the way for future research on the socio-economic impacts of flooding in Boma and possible adaptations to climate change. The results provide a solid basis for concrete actions aimed at protecting vulnerable communities and building resilience to extreme climate events.

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## Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

## Ethical Considérations

This article was prepared in accordance with ethical research principles, ensuring compliance with current standards. It is important to note that no human or animal data were used in this study, ensuring full compliance with ethical requirements. The authors also declare that they have no conflicts of interest regarding this research, which reinforces the study's credibility. The data used for this analysis were obtained ethically and legally, complying with all relevant regulations. Finally, the study results were presented honestly and transparently, without any data manipulation, to ensure the scientific integrity of the entire work.

## Authors contributions

Each author played a key role in the development and finalization of the research article.

A.M.N. was responsible for drafting and preparing the original version. He also focused on data collection and analysis and validated the final version.

C.N.U.-D.-M. was responsible for reviewing the survey, helped improve the quality of the original version, and performed the final revision, ensuring the article was ready for publication. Finally,

F.M.I. and G.D.N. oversaw the entire process, ensuring that all steps were followed correctly.

All authors have read and approved the final version of the manuscript.

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## References

- Abderraouf Benaoudj, Benina TOUAIBIAPierre HUBERT. (2014). Floods in the M'Zab Valley (South Algeria): Genesis and Prediction. *Scientific and Technical Review*, 24 & 25.
- Ago, E. E., Petit, F., & Ozer, P. (2005). Flood Analysis Downstream of the Nangbeto Dam on the Mono River (Togo and Benin). *Geo-Eco-Trop: International Journal of Tropical Geology, Geography and Ecology*, 29.
- Breil, P. (2018). The value of wetlands for runoff flood prevention. *Sciences Eaux & Territoires, Issue 26(2)*, 62–65. <https://doi.org/10.3917/set.026.0062>
- Cafarelli, F. (2023). The Resilience of Territories Exposed to Natural Hazards - The Law in the Face of Risks, *Proceedings of the Clermont-Ferrand Conference*, 7-8, 2021.
- Chen, R. J. A. a S., Savi, D. a, & Djordjevi, S. (2013). Fast Simulation of Sewer Flow Using Cellular Automata. *In Novatech*, pp. 1–10.
- Derdour, A., Bouanani, A., & Babahamed, K. (2017). Flood Typology in Semi-Arid Environments: The Case of the Ain Sefra Watershed (Ksour Mountains, Saharan Atlas, Southwest Algeria). *Larhyss Journal*, 29, 1266–2002
- Douvinet, J., Defosse, S., Anselle, A., & Denolle, A. S. (2011). Mayors and Flood Risk Prevention Plans (PPRI). *L'Espace géographique*, 40(1), 31-46.
- Foen. (2005). Ordering of prov. flood streams and high water levels - High water level August 2005. *Internal report*, 1–3.
- Furuho, C., Perrin, C., Andreassian, V., Lamblin, R., Dorchies, D., & Berthet, L. (2015). Collaborative Dynamics between Operational and Scientific Actors for Improving Flood Forecasting Systems in France. *Sciences Eaux & Territoires, Issue 17(2)*, 40–45. <https://doi.org/10.3917/set.017.0040>
- Guelbeogo, S., Ouedraogo, L., & Ilboudo, S. (2023). Flood forecasting in the Kou watershed, Burkina

- Faso. *International Journal of Biological and Chemical Sciences*, 17(3), 1131–1146. <https://doi.org/10.4314/ijbcs.v17i3.29>
- Ibouraïma, Y., Pierre, L., Climat, P., & Développement, E. (2019). Climate Change and Flooding in the Municipality of Ouinhi in Southeastern Benin: Transforming Disasters into Opportunities. *Revue Espace Géographique et Société Marocaine*, 27, 187–208.
- Kayser, G., Zeimet, F., Manso, P., Schleiss, A., & Jordan, F. (2019). Synergies between hydropower generation and flood protection: A case study of the Sihl in Switzerland. *La Houille Blanche*, 105(3–4), 102–115. <https://doi.org/10.1051/lhb/2019028>.
- Koungbanane, D., Zahiri, P. E., Sourou, H., Totin Vodounon, H. S., Amoussou, E., Lare, L. Y., & Koubodana, H. D. (2020). Frequency analysis and determination of pluvio-hydrological flood risk thresholds in the Oti watershed in Togo. *Afrique SCIENCE*, 17(1), 73–88.
- Lang, M., Darienzo, M., Le Coz, J., & Renard, B. (2022). Evaluation of uncertainties and homogeneity in long flood discharge series on the Rhine at Basel (1225–2017) and Maxau (1815–2018). *LHB: Hydrosience Journal*, 108(1). <https://doi.org/10.1080/27678490.2022.2053313>
- Laraque, A., Le Coz, J., Moukandi N’kaya, G. D., Bissemo, G., Ayissou, L., Rouché, N., Gulemvuga, G. (2022). Rating curves of the Congo River in Brazzaville and Kinshasa. *LHB*, 108(1). <https://doi.org/10.1080/27678490.2022.2082338>
- Lavabre, J., Fouchier, C., Folton, N., & Gregoris, Y. (2003). SHYREG: A method for regional flood discharge estimation. Application to the French Mediterranean regions. *Engineering, Special*, 97–111.
- Magrin, G., & Mugelé, R. (2020). The Anthropocene Loop in the Sahel: Nature and Societies in the Face of Major Environmental Projects (Great Green Wall, Safeguarding Lake Chad). *Belgeo. Belgian Journal of Geography*, (3). <https://doi.org/10.4000/belgeo.42872>
- Mampuya Nzita, A., Phuku Phuati, E., Muanda Ngimbi, R., Dituba Ngoma, G., Masiala Mavungu, N. (2024). Study of Lateral Vibrations in Turbine-Alternator Unit 5 of the Inga 2 Hydroelectric Power Plant. *IgMin Res*, 2(4), 255-260. <https://doi.org/10.61927/igmin173>
- Nzita, A. M., Mizengi, L. M., Ndiwulu, G. W., Ngoma, G. D., Uмба-di-Mbudi, C. N. Z., Ngimbi, R. M., and Phuati, E. P. (2024). Statistical analysis of the aging of electrical components in group 6 of the Inga 2 hydroelectric power plant following sudden shutdowns. *Computational and experimental research on materials and renewable energies*, 7(2), 78-92. <https://doi.org/10.19184/cerimre.v7i2.51268>
- Pierrefeu, G., Roumieu, P., Delamarre Pobanz, K., & Peteuil, C. (2022). Innovative hybrid approach for measuring flow rates in the pipes of medium-head hydroelectric groups. *LHB*, 108(1). <https://doi.org/10.1080/27678490.2022.2163200>
- Rey, F., Breton, V., Breil, P., & Mériaux, P. (2018). Nature-Based Solutions for Combining Flood Prevention with Integrated Management of Aquatic Environments. *Sciences Eaux & Territoires*, 26 (2), 36–41. <https://doi.org/10.3917/set.026.0036>
- Rode, S., Ribas Palom, A., Saurí, D., & Olcina Cantos, J. (2022). Adapting Territories to Flood Risk in France and Spain: Towards New Practices for Flood-Prone Area Management?. *In Annales de géographie*, 1, 44-71.
- Sene, S., & Ozer, P. (2002). Rainfall Evolution and the Relationship between Floods and Rainfall Events in Senegal. *Bulletin of the Geographical Society of Liège*, 42, 27–33.
- Vuni, A., Aloni, J., Lelo, F., and Nzau, M.C. (2020). Kalamu to Boma, a River Under Attack: Diagnosis for a River Contract. *Bulletin of the Centre for Geological and Mining Research*, 8, 195–213.