10.3197/JPS.63799953906871

PEER REVIEWED ARTICLE

Socio-Environmental and Physical Factors of Flood Risk in African Cities: An Analysis of Vulnerabilities in Two Contrasting Neighbourhoods in Abidjan, Côte d'Ivoire

Stéphanie Dos Santos,[1] Abdul Wahab Karamoko,[2] Attoumane Artadji[3] and Eric-Pascal Zahiri[4]

Abstract

The literature on vulnerability to flooding highlights the multiple dimensions of risk factors. However, little research has analysed the joint effects of environmental and social variables on flood risk at the household level in African cities. We use an interdisciplinary approach to analyse the differentiated significance of these dimensions for the status of 'flood victim' in Abidjan, the major city of Côte d'Ivoire. The data used were collected in a survey of 503 households residing in two contrasting neighbourhoods of Abidjan. Modelling data with logistic regressions, the results show that physical variables (the slope of the housing plot), environmental variables (liquid and solid waste disposal) and social variables (the gender of the head of household or the composition of the household) are factors jointly associated with flood risk. The multidimensional nature of vulnerability

1 Population Environment Development Laboratory (LPED), Institute of Research for Development (IRD), Aix-Marseille University. Email: stephanie.dossantos@ird.fr

2 Insitut de Géographie Tropicale (IGT), Université Félix Houphouët-Boigny. Email: kara-wab@hotmail.fr

3 Population Environment Development Laboratory (LPED), Institute of Research for Development (IRD), Aix-Marseille University. Email: attoumane.artadji@ird.fr

4 Laboratoire des Sciences de la Matières, de l'Environnement et de l'Energie Solaire (LASMES), Université Félix Houphouët-Boigny. Email: zahiripascal@gmail.com

at the household level must be seen as a challenge faced by public authorities in post-disaster management.

Keywords: vulnerability, flood, cities, sub-Saharan Africa, interdisciplinarity.

Introduction

Worldwide, extreme events related to climate are becoming more and more frequent, mainly because of an ever-increasing number of floods and storms. From 1995 to 2015, floods alone represented 47 per cent of all climate-related disasters, affecting more than two billion people (UNISDR 2015). In Africa, cities are particularly vulnerable to flooding (Douglas et al. 2008).

As early as 1942, White's pioneering doctoral thesis challenged the idea that natural hazards are best addressed by engineering solutions (White 1946). Nevertheless, in the four decades thereafter, a technology-focused paradigm prevailed: understanding a hazard with the geosciences and technological progress (measured and determined by the intensity of the rainfall) was sufficient in itself to reduce the risks encountered by human populations (Becerra 2012). That said, since the 1990s, the need to consider the vulnerability of populations in risk-management analysis has been widely recognised. Turner et al. (2003), and later Birkmann and Wisner (2006), have provided a comprehensive conceptual framework that integrates the multidimensional nature of vulnerability at different scales and in different contexts.

In cities, physical factors related to exposure are decisive with respect to the forms and modes of urban planning: ground coverage, density of the built environment, state of saturation of the ground depending on its topographical position (lower, intermediate or upper part of the catchment basin) or the piezometric level, etc. Urban populations and the built environment are recognised as hotspots with regard to risk of flooding, presenting greater 'probabilities of damage' (Douglas and Wildavsky 1982) related to climate change (McCarthy, Best and Betts 2010; Wilby 2007). In sub-Saharan towns, the unprecedented urban growth observed – most of the times managed by inadequate or unsuitable policies – meets with an increase in risks related to meteorological extremes. These events can have disastrous consequences for most of the population living in risk areas (Kabisch et al. 2015; Rufat et al. 2015), thus exacerbating already existing socioeconomic inequalities (Reckien et al. 2017).

In this respect, there is an abundant literature providing evidence that the factors contributing to vulnerability must also be explored in terms of socio-demographic and economic conditions (Bigi et al. 2021). The articles by Blaikie and colleagues (2004) and Cutter and colleagues (2003) were outstanding in this regard: they found that rainfall, fluvial or coastal flooding in towns intersects with informal settlements, urban poverty, marginalisation and population density in areas exposed to these hazards (Dodman 2019; Douglas et al. 2008; Magadza 2000). Kit et al. (2011) confirmed that slums in Hyderabad, India, are often located in areas of rainwater accumulation. Ajibade and McBean's (2014) work in slum communities in Lagos, Nigeria, also highlighted how aspects such as limited access to housing or weak land rights push populations to settle on land potentially at greater risk of flooding. Generally, research has shown that extreme rainfall events affect the lower-income classes more, as is the case in New Delhi, India (Reckien, Wildenberg and Bachhofer 2013).

Accordingly, studies have assessed flood risk by looking at: 1) physical vulnerability and likelihood of damage, 2) the vulnerability of structures and goods or 3) the risk to death of the populations. The hypothesis is generally that social vulnerability is homogeneous for any population studied (Koks et al. 2015), often populations with low socioeconomic status. An important contribution is the article by Koks and colleagues (2015), which examines flood risk in Rotterdam, Netherlands, since their analysis combines hazard, exposure and social vulnerability at the household level. However, although this article is an important contribution, the variables of social vulnerability that are taken into account are relatively limited. In addition, this study adopts an approach based on the creation of an index of social vulnerability, mainly developed in research on flood risk (Cutter et al. 2013). Yet, although it presents methodological advantages, notably in view of the parsimony of statistical models, using an index based on grouping together a set of variables cannot pinpoint what specific factors related to social vulnerability are actually at stake.

Finally, the study area is one last methodological issue in the literature. In interdisciplinary projects (social sciences and the earth sciences), the study area is often defined by the hazard risk alone (Léone and Vinet 2006). The result is a descriptive analysis of the risk factors in the areas affected by the hazard. However, any risk-mitigation policy should be based on the differentials of risk, that is, by comparing the groups of affected households with those that have not experienced the phenomenon. Otherwise, it is impossible to identify the relevant factors.

In the present article, we aim to fill these gaps and highlight the differentials of risk in these disasters, combining physical and environmental with socio-demographic factors in two contrasting neighbourhoods in Abidjan, the major city of Côte d'Ivoire. In the years to come, twenty-six per cent of the city's area might be exposed to flooding or is at risk from landslides due to heavy rain (OCHA 2014).

The research question is: what are the joint effects of the different dimensions of vulnerability to flooding, all things being equal, in a West African city? Combining earth and social sciences perspectives helps to better understand how to cope with different forms of vulnerability (Bohle 2007). We thus explore the combined impact of three dimensions of vulnerability operationalised by physical variables, environmental living conditions and socio-demographic variables, all at the household level. The period of analysis is 2009–2018. A four-stage logistic regression analysis enables us to observe the different dimensions of vulnerability in all their diversity.

Before presenting the analytical method used to identify the factors associated with flood-victim status, we will outline the study area of this research. We will then present some descriptive results, followed by the modelling results. Finally, the discussion will focus on the factors that seem most convincing in explaining physical and social vulnerability to flooding.

Study Area

This study was carried out as part of the project EVIDENCE (Évènements *Pluvieux Extrêmes, Vulnérabilités et Risques Environnementaux: Inondation et Contamination des Eaux*),[5] which is an interdisciplinary project (demography, geography, hydrology and physics) that seeks in particular to analyse the multiple vulnerabilities related to extreme hydro-climatic events in the district of Abidjan, the economic capital of Côte d'Ivoire.

5 More information on the project can be found here: http://www.evidence-ci.org/.

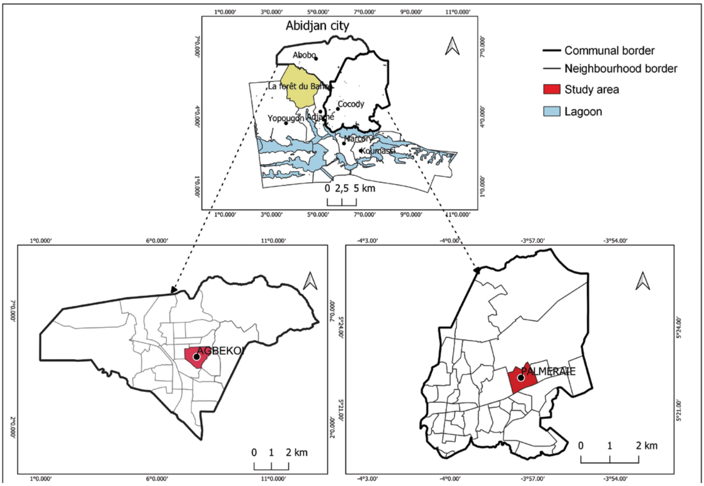
Côte d'Ivoire is a country in West Africa with a Human Development Index (HDI) of 0.538, ranked 162nd out of 189 countries. Its HDI value is higher than the mean within the group of countries with low human development (determined as 0.513) but lower than the mean of the countries of sub-Saharan Africa (which is 0.547). Furthermore, significant socioeconomic inequalities may be observed: the HDI value of Côte d'Ivoire plunges to 0.346 if these inequalities are taken into account. These inequalities are greater than in the rest of sub-Saharan Africa: the coefficient of human inequality is 35.3 per cent for Côte d'Ivoire and 30.5 per cent for the whole of Sub-Saharan Africa (PNUD 2021).

The district of Abidjan is characterised by significant urban growth. Within sixty years, the population of Abidjan multiplied by 27 and thus increased from 192,000 in 1960 to 5.2 million inhabitants in 2020, a result of both natural growth and migration, mainly from the interior of the country. According to the median demographic projections of growth, the city will have reached almost eight million inhabitants by 2035 (UNDESA 2018).

In this context, two neighbourhoods have been selected as they meet the requirements of the interdisciplinary team of the EVIDENCE project, namely being situated in a different catchment area and presenting contrasting topographical and socioeconomic features. The selected neighbourhoods (Figure 1) are Agbekoi, situated in the municipality of Abobo, and Palmeraie, in the municipality of Cocody. These two municipalities were the most heavily impacted by past flooding events, according to a report by the United Nations Office for the Coordination of Humanitarian Affairs, with 12,500 people permanently exposed in Abobo and 40,000 in Cocody (OCHA 2014). Furthermore, the socioeconomic conditions of the inhabitants of these two municipalities are extremely different. A 2013 UNDP survey estimated that 80% of the population of Abobo lives in slums that were upgraded and 16% in informal settlements, where socioeconomic and housing conditions are below-average by the standards of the municipality. No residential housing was recorded. In contrast, in Cocody, 21% of the households lives in a residential area, and 42% in economic housing,[6] the remainder living in slums, if upgraded or not. With regard to the environmental living conditions, only 4% of the households in the municipality of Abobo are connected to the water-supply network, compared to 18% in Cocody (PNUD 2013).

6 Economic housing is social, collective and affordable housing generally managed by state or semi-state companies.

Figure 1. Localisation of Agbekoi (bottom left) and Palmeraie (bottom right) neighbourhoods in the city of Abidjan (top)

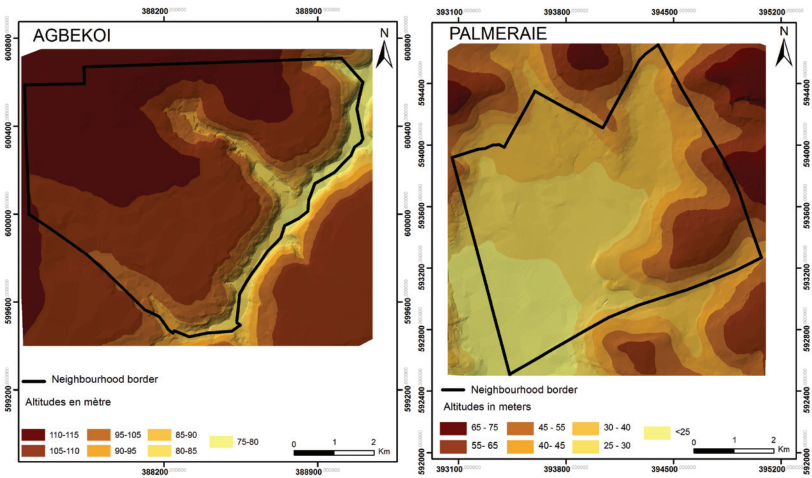


SOURCE: FIGURE BY THE AUTHORS. DATA FROM INS.

Figure 1a shows the location of the neighbourhood of Agbekoi in the centre-east of the municipality of Abobo. The relief of Agbekoi is dominated, from the northwest towards the northeast, by a plateau (Figure 2a). From the northeast southwards, there is a dried-up ravine with one branch. This natural depression of the land's surface divides the neighbourhood into two areas. The topographical profile of Agbekoi slopes progressively from the northwest (where the highest point is close to 110 metres above sea level) towards the southeast (where the altitude is less than 80 metres). The neighbourhood extends over 135 hectares, with a high population density estimated at 600 inhabitants per hectare (INS 2022).

Palmeraie is situated in the centre-east of the municipality of Cocody (Figure 1.b), in the catchment basin of Bonoumin-Palmeraie (Figure 2b). The relief of Palmeraie is marked by a valley, which extends over a width of 1,200 metres and a length of 2,000 metres. In this valley, the altitude ranges from 25 metres to 45 metres. The eastern part of this neighbourhood is the highest area, with an altitude of more than 65 metres. From east to southwest, the topographical profile of Palmeraie is a gradual slope. The population density is much lower than at Agbekoi, estimated at 170 habitants per hectare, over an area of 236 hectares (INS 2022).

Figure 2. Relief of Agbekoi (left) and Palmeraie (right)

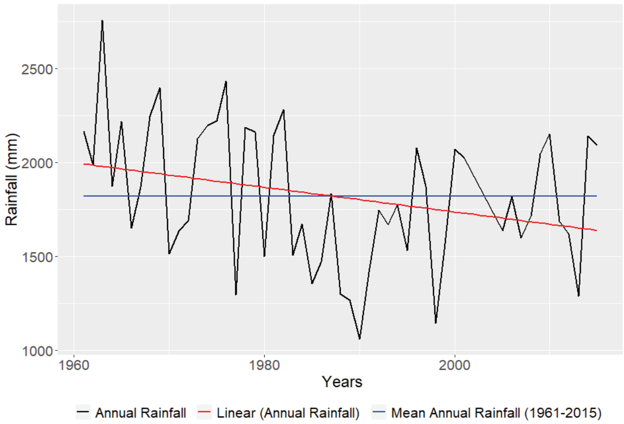


SOURCE: FIGURE BY THE AUTHORS. DATA FROM CCT/BNETD

Finally, regarding climatic and in particular pluviometry, the district of Abidjan has a sub-equatorial climate, with two rainy seasons and two dry seasons. During the long rainy season, from March to July, the rains account for two-thirds of the annual rainfall (1,922 millimetres). This rainy season is followed by the short dry season, lasting from August to September. A second peak in the rainfall is the short rainy season, from October to November, followed by the long dry season from December to March. The mean monthly temperatures range from 24.2 degrees Celsius in August, the coldest month, to 27.4 degrees Celsius in March, the hottest month (Kouassi et al. 2018).

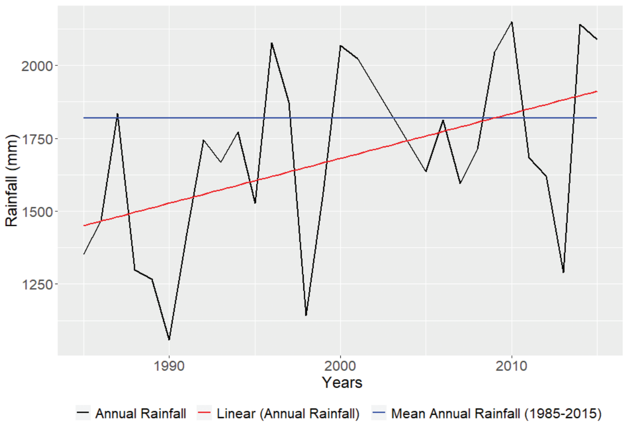
Figure 3 shows the historical data from 1961 to 2014 (Sodexam 2016). The mean annual rainfall was 1819 millimetres over this period. Based on the Mann-Kendal test, determination of the mean trend shows a mean drop in the rainfall over this period of almost 70 years, which corresponds with a declining trend observed in the subregion (Lebel et al. 2000). Nevertheless, looking at a more recent period, from 1985 to 2015, an increase in the mean trend of rainfall (Figure 4) can be observed, which reflects an increase in the occurrence of extreme events (Zahiri et al. 2016; Attoumane et al. 2022) causing recurrent flooding (Kouamé et al. 2022).

Figure 3. Annual rainfall in Abidjan (1961–2015)



SOURCE: FIGURE BY THE AUTHORS. DATA FROM SODEXAM

Figure 4. Annual rainfall in Abidjan (1985–2015)



SOURCE: FIGURE BY THE AUTHORS. DATA FROM SODEXAM.

Methods

Data Collection

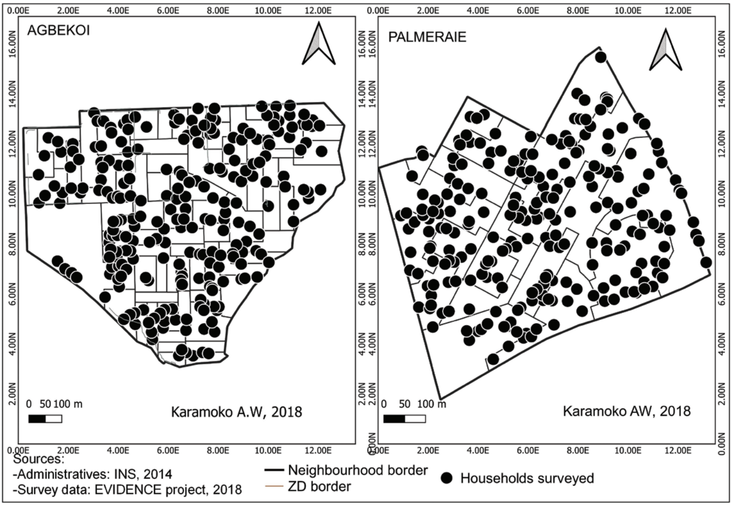
The data used was collected through a household survey as part of the EVIDENCE project. A sample of 503 households (Figure 5) was randomly selected based on two geographical criteria, in the absence of a survey database available in 2018. In the first stage, a preliminary field-sampling study provided the basis for identifying the census district (CD) that is or is not exposed to flood risk in the two neighbourhoods. In a second step, the number of households to survey was calculated in proportion to the surface area of the level of risk in both neighbourhoods. In Agbekoi (Figure 5.a), 58% of the surface area is exposed to flood risk; 146 households were randomly selected in the CD exposed to flood risk and 116 households in the CD not exposed (42% of the surface area of Agbekoi). In Palmeraie (Figure 5b), 136 households were randomly selected in the CD exposed to flood risk (covering 54% of its surface area) and 115 households in the CD not exposed (46% of the surface area). In the absence of an exhaustive, up-to-date list of households in the two neighbourhoods, a random selection was made using the software QGIS. In order to localise the buildings or residential courtyards of the inhabitants, random spatial data were projected onto an image from the satellite Quickbird from 2015. A relocalisation of the spatial data was performed if they were localised in uninhabited areas (empty plot, garden, business building, etc.).

Once a house was localised, one household on the ground floor was surveyed per localisation through an interview with the head of the household. This survey was carried out from December 2018 to January 2019.

Data Analysis

The aim was to estimate the net effect, all other factors being equal, of different independent variables related to the physical characteristics, the domestic environment and the socio-demographic characteristics of the household, on the status of flood victim. The status of flood victim was conceptualised by a composite dependent variable created on the basis of variables identifying material damage (fallen walls, split walls, damage to the roof, loss of consumer goods or vehicles), or corporal damage caused by flooding of the surveyed household over the ten years before the survey, from 2009 to 2018. The dependent variable is binary: the household has been affected by flooding at least once during this period, or the household has not suffered any material or corporal damage, and is, therefore, non-flood impacted.

Figure 5. Spatial distribution of households surveyed in Agbekoi (left) and Palmeraie (right)



SOURCE: FIGURE BY THE AUTHORS. DATA FROM INS AND EVIDENCE.

We have used the following logistical regression:

$$ln(q_i/1\text{-}q_i)=\beta_0 + \beta_i x_i$$

Here, q is the probability of being declared impacted for the i^{th} household, β0 is the base constant, βi is a series of unknown coefficients and xi is a set of independent variables. The coefficients estimated (βi), once made exponential, are interpreted as the chances of being an impacted household (qi/1-qi), with certain characteristics relative to the chances of being impacted in a reference group of households: that is what is known as the relative chances or odds ratios (OR).

In order to characterise the factors of physical vulnerability, three variables were chosen: (1) the presence of a gutter right in front of the house to evacuate rainwater; (2) the distance between the household and the nearest drainage system (large or small pipes, ravines and streams; continuous variable); (3) the slope[7] calculated on the basis of a 12 metres ALOS PALSAR[8] digital model. The literature has identified these variables as factors of vulnerability to flooding (Ashraf 2012; Bigi et al. 2021).

We then hypothesised that two types of household characteristics determine the socio-environmental vulnerability. Firstly, the variables relate to the environmental dimension of the living conditions, that is, those related to the domestic environment, to the habitat and the management of the salubriousness of the living environment: the type of roofing, ground and walls as well as the management of sewage and solid waste. Next, we investigated the socio-demographic characteristics of each head of household (sex, age, level of education, place of birth, length of residence in the neighbourhood, residential status), the number of people living in the household and the standard of living[9]. These variables are related to different dimensions of the socio-environmental vulnerability of households (Dos Santos, Peumi and Soura 2019; de Sherbinin and Bardy 2015; Bigi et al. 2021).

To better understand the net effects of the factors related, on the one hand, to the physical characteristics and, on the other, to the household, the variables were introduced separately in the models, block by block, which enabled us to compare the coefficients between the different equations. The status of flood victim was thus modelled step by step. Model 1 tests the variables potentially related to physical vulnerability. Model 2 integrates the variables that operationalised the socio-environmental vulnerability. Model 3 tests the variables dealing with the socio-demographic vulnerability of the household. Finally, Model 4 tests all the above-mentioned variables, integrating the variable ‘neighbourhood’ to capture any unobserved contextual effects, as we have no such variables in our database. This allowed measuring the specific effect of each independent variable, all other things being equal, including the non-observed heterogeneity on the neighbourhood level.

7 The continuous variable ‘slope’ was then classified into three modes by the quantile method to obtain three levels of slope: low, medium and high.

8 University of Alaska Fairbanks, Alaska Satellite Facility, https://asf.alaska.edu/ (accessed 22 Jun. 2023).

9 The standard of living index was calculated based on consumer goods (television, radio, car, kitchen equipment, etc.) owned by the household. This index was then classified into three modes by the quantile method to obtain three standards of living: low, medium and high.

The option 'cluster' available in the Stata software was applied on the variable identifying each CD (n=85) to take into account the resemblance and thus control for the non-independence of the households in the same CD. In this way, the standard errors presented are adjusted and are thus more robust in the four successive types of models.

Results

Descriptive Results

The descriptive results show that with reference to the period from 2009 to 2018, the households surveyed in Agbekoi less often state that they have been flood victims in their homes than the households in Palmeraie, with a proportion of flood victims of 13.5 per cent and 39.4 per cent, respectively (Table 1).

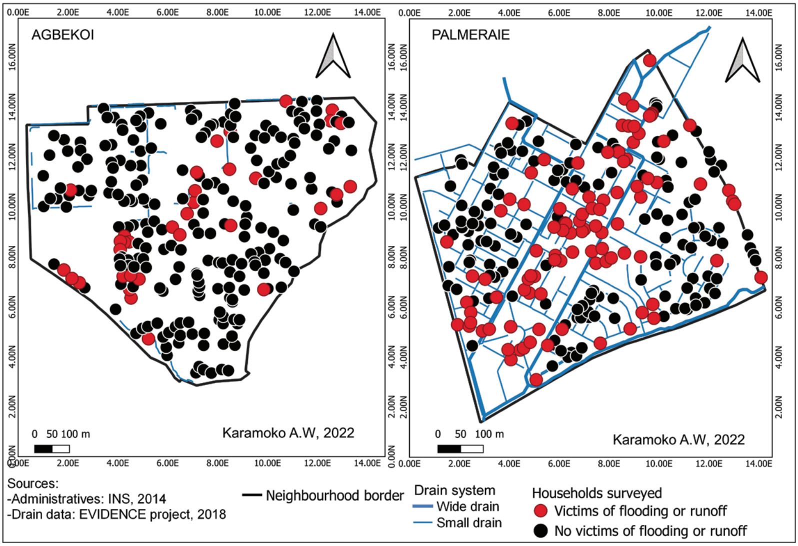
Table 1. Distribution and frequencies of households by flooding victim status – Abidjan, Côte d'Ivoire

Flooding victim	**Agbekoi**		**Palmeraie**		**TOTAL**	
	nb	**%**	**nb**	**%**	**nb**	**%**
Yes	34	13.5	99	39.4	133	26.4
No	218	86.5	152	60.6	370	73.6
TOTAL	252	100.0	251	100.0	503	100.0

SOURCE: FIGURE BY THE AUTHORS. DATA FROM EVIDENCE

In Agbekoi, the households affected by flooding during the period from 2009 to 2018 are mainly located along the axis running from the northwest to the centre and the southwest of the neighbourhood. They are located far away from any kind of drainage pipes, which are mainly situated in the northwest and represent the only infrastructure for the whole neighbourhood (only 3.4 kilometres of pipes; Figure 6.a). In Palmeraie, most of the households affected by flooding are located in the centre of the neighbourhood, from the northwest to the southeast, not far from the main rainwater drainage system (Figure 6.b). This neighbourhood has a network of main drainage pipes extending over about 6.4 kilometres and a network of secondary pipes of less than 35.6 kilometres.

Figure 6. Spatial distribution of households surveyed in Agbekoi (left) and Palmeraie (right) and drainage pipes



SOURCE: FIGURE BY THE AUTHORS. DATA FROM INS AND EVIDENCE

The descriptive analysis of some social characteristics of the surveyed households also shows stark contrasts between Agbekoi and Palmeraie. For example, the analysis of the standard of living index, measured based on the consumer goods owned by the household, shows that more than half (52.8%) of those surveyed in Agbekoi have a low standard of living, whereas more than half (58.6%) of surveyed households in Palmeraie have a high standard of living. Similarly, regarding the level of education of the head of the household, it is mainly the higher level that is observed in Palmeraie (61.8%), whereas in Agbekoi, 28.2% of households represent this level of education.

Multivariate Results

Table 2 shows the results of the multivariate analysis, including the four stages described in the progressive inclusion of the sets of variables, representing the different dimensions of vulnerability in our analytical framework.

Table 2. Frequencies and multivariate models with estimated net effects [odds ratios and adjusted significance levels] on the status 'affected by flood', taking into account physical, environmental/housing, socioeconomic and neighbourhood variables – Abidjan, Côte d'Ivoire

Independent Variables	*Frequencies*	Model 1	Model 2	Model 3	Model 4
Outdoor gutter (yes)	*(28.8)*				
No	*71.2*	0.58**			0.80
Distance to the rainwater pipe (continuous var.)		0.99***			0.99
Slope (small)	*(34.4)*				
Medium	32.4	0.70			0.64*
High	33.2	1.22			0.95
Roof (metal or tile)	*(72.2)*				
Concrete slab	*25.6*		1.56		0.71
Plastic sheet	*2.2*		1.22		1.62
Wall (cement or brick)	*(91.2)*				
Wood	*8.8*		1.21		0.10***
Ground (tiles)	*(45.3)*				
Cement	*45.5*		0.98		2.12**
Other (sand, etc.)	*9.2*		3.07**		6.84***
Wastewater management (sewer)	*(44.1)*				
Septic tank	*36.4*		0.84		2.68**
Other (thrown outside, street, etc.)	*19.5*		0.96		3.38**
Solid waste disposal (public sector collection system)	*(25.9)*				
Private sector collection system	*42.7*		1.89**		1.62*
Other (thrown outside, street, etc.)	*32.4*		0.60		1.10
Sex of the household head – HH (male)	*(80.1)*				
Female	*19.9*			1.61*	2.27***
HH's age (less than 45 years)	*(40.2)*				
45-59 years	*35.0*			1.29	1.32
60 years and over	*24.8*			1.17	1.33
HH's education (none)	*(24.8)*				
Primary	*15.9*			1.41	1.39
Secondary	*22.5*			1.87*	1.68
Higher	*36.8*			1.66	0.83

HH's place of birth (Abidjan)	*(34.6)*		
Other towns	*38.2*	1.12	0.89
Rural area	*17.7*	0.95	0.95
Abroad	*9.5*	2.11*	1.30
HH's duration of residence in the neighborhood (< 10 years)	*(30.0)*		
10-19 years	*31.6*	1.02	1.27
20 years and over	*38.4*	0.53+	1.04
HH's residential status (owner)	*(46.1)*		
Tenant	*40.6*	0.65	0.93
Hosted	*13.3*	1.25	1.58
Number of usual members in the household (1-4)	*(24.4)*		
5-9	*53.3*	1.47+	2.03**
10 and over	*22.3*	1.03	1.60+
Life level index (low)	*(39.2)*		
Medium	*28.6*	1.28	1.60
High	*32.2*	1.18	0.69
Neighbourhood (Agbekoi)	*(50.1)*		
Palmeraie	*49.9*		40.0***

Reference category in parenthesis. Significant levels : *** p<1% ; ** p<5% ; * p<10% ; + p<15%

SOURCE: FIGURE BY THE AUTHOR. DATA FROM EVIDENCE

In Model 1, some variables related to the physical vulnerability are linked to the flood-victim status during the period from 2009 to 2018. These variables represent the presence of a gutter in front of the household's dwelling and the distance from drainage pipes. Therefore, households that do not have a gutter to evacuate rainwater in front of their dwelling are less at risk of having experienced damage than households that have a gutter in front of their dwelling (OR=0.58; p<5%). The same applies to the distance between dwelling and the next drainage pipe: the farther the household is from the pipe, the lower the risk of having experienced damage. We also found that the slope of the ground on which the dwelling is built does not seem to be statistically related to flood-victim status.

The variables dealing with the environmental vulnerability were introduced in one block in Model 2. The results show that two variables in this group are linked to flood-victim status. Households where the floor is not made of solid material (sand, earth, etc.), are three times more likely to have experienced damage than households living in a dwelling where the ground is covered with paving. Furthermore, households that use a private waste-collection service are twice as likely to have been flooded than those that use a public sector waste-collection service.

Regarding the personal characteristics of the head of household, reflecting social vulnerability, the statistically significant odds ratios obtained in Model 3 are those of sex, level of education, place of birth, duration of residence in the neighbourhood and a variable representing the composition of the household, i.e., the size of the household. For example, households where the head is a woman are more at risk of flooding than households where the head is a man (OR=1.61; $p<10\%$). Similarly, the level of instruction variable is statistically significant: the general gradient can be interpreted as if the households where the head did not go to school are less at risk of becoming a flood victim than other households. This especially applies to households where the head continued up to high-school level: these are twice as much at risk of being affected by flooding than households where the head did not go to school ($p<10\%$). In addition, households where the head has lived in the neighbourhood for more than twenty years are half as much at risk of flooding than households where the head has lived in the neighbourhood for less than five years. In contrast, households where the head was born outside Côte d'Ivoire are twice as much at risk of being a flood victim than households where the head was born in Abidjan. Finally, households of medium size (composed of nine people) were one and a half times more likely to have been affected by flood than those of small size (composed of less than five people).

These results should nonetheless be qualified by introducing the variable 'neighbourhood' since, as we have seen, these two neighbourhoods present different characteristics that must be taken into account, other things being equal. Model 4 shows the odds ratios after introducing the neighbourhood variable, which itself has a significant effect on a certain number of variables and confirms the very high-risk differential between these two neighbourhoods. During the period from 2009 to 2018, a household resident in Palmeraie had a 40 times greater risk of being impacted by flooding than a household living in Agbekoi, all other physical and socio-environmental characteristics being equal.

The variables concerning physical vulnerability are thus affected by the variable 'neighbourhood' in the complete model. In particular, the variables relating to the infrastructure of the neighbourhood (gutters and drainage pipes) are no longer statistically associated with the likelihood of being flooded. On the other hand, all else being equal, whichever neighbourhood, the effect of the slope of the ground where the dwelling is located is statistically significant: households situated on slopes ranging from 1.7 to 3.4 degrees are less at risk of flooding than households situated on a slope of less than 1.7 degrees (OR=0.64; p<10%). Analyses of the individual neighbourhoods (not shown) highlight that the slope has the greater effect in Agbekoi.

The introduction of this neighbourhood variable also has an important effect on the variables related to the vulnerability associated with the environmental dimension of the living conditions. This is particularly apparent with the variables of the type of wall, the type of floor and the sewage management, whose effects now become highly significant. Thus, households that do not have a paved floor and those that do not have a sewer for the removal of wastewater are at greater risk of flooding, to a highly significant degree, compared to the reference modes, whatever the neighbourhood. In contrast, households that have wooden walls are much less likely to have been impacted by flooding than those with walls of cement or brick (OR=0.1; p<1%). It should be noted that almost all of the households whose dwellings have wooden walls are located in the better-off neighbourhood of Palmeraie (91%) and are among the poorest in this neighbourhood (91% have a low standard of living index).

Finally, the introduction of the neighbourhood variable has a significant impact on the effect of variables related to social vulnerability and, in particular, the variable sex of the head of the household. The effect of this variable is enhanced both in the odds ratio and in the degree of confidence we can have in its interpretation: between Model 3 and Model 4, the differential between the fact of being a male or a female head of household is increased (OR = 2.27; p<1%), to the detriment of households headed by women. Moreover, stratified analysis by neighbourhood (results not shown) confirms this effect of the sex of the head of household in the two neighbourhoods studied.

This confirmation of the differentials is also observed for the variable that operationalises the family structure: comparing Model 3 and 4, we confirm that large families had a greater risk of becoming flood victims during the period from

2009 to 2018 than households with less than five people.[10] Thus, the introduction of the neighbourhood variable no longer offers a basis for confidently interpreting the effects of the other variables related to social vulnerability, proving the importance of the contextual effect, in this case the type of neighbourhood, in the interpretation of vulnerability to flooding.

Discussion

Based on econometric models (logistic regressions), our results highlight two major contributions. The first one is that there are several dimensions combined of flooding vulnerability. Using a multi-criteria approach, we have shown how vulnerability is a process that should be analysed at different spatial scales and in relation to the various aspects of sustainable development (social, economic and environmental). This concept should take into account the probability of undergoing a shock, either physically or materially, by the deterioration or loss of the means of subsistence (Blaikie et al. 2014).

The second one is the important contextual effect of differentials on the vulnerability to flooding. First of all, about the latter point, the results relate to human-security framing (O'Brien et al. 2007) having conceptualised the necessity of having an analysis that can detect the discriminating contextual effect of the neighbourhood and, in doing so, reduce the non-observed heterogeneity of this type of analysis. Thus, our results show it is essential to perform a disaggregation of the levels of analyses at a fine scale, neighbourhoods of towns but also at the household scale (Koks et al. 2015): (1) the effect of neighbourhood *per se* is dominant in our results, each neighbourhood representing a very different level of risk; (2) the introduction of the neighbourhood variable alters the effect of certain variables of vulnerability measured at household scale; (3) the effects of different dimensions of vulnerability are happening simultaneously.

Concerning the variables related to physical vulnerability, the results show that, regardless of the neighbourhood, a household living on a slope that is neither too steep nor too flat benefits from a protective effect on the risk of suffering flood damage. In fact, the slope has an important physical effect, notably about the rate of runoff of rainwater, and is highly sensitive to rainfall events of different

10 This effect of the household's family structure seems to be stronger in the Palmeraie district (results not shown).

duration and frequency (Ashraf 2012). Nevertheless, the phenomena observed are divergent: steep slopes generally tend to induce runoff, whereas flatter slopes may be associated with water stagnation in the case of a drainage system failure.

In this respect, the effect of the distance from drainage pipes is worth discussing, even though it is not statistically significant upon introducing the neighbourhood variable. With regard to this aspect of the physical vulnerability, the two neighbourhoods present major differences, as we have seen in the 'Descriptive Results' section: the neighbourhood of Palmeraie is equipped with drainage pipes (Figure 6b). It is as if the neighbourhood variable captured the effect of the drainage pipes and gutters in front of the dwelling to evacuate rainwater. Thus, in this neighbourhood, a completely counterintuitive phenomenon is at play: the farther the households are from the drainage pipes (or if they do not have a gutter in front of the dwelling), the less likely to be a flood victim, whereas in theory, the presence of infrastructure should lead to the opposite effect. It might result from under-dimensioning the drainage network for rainwater being exacerbated during extreme rainfall (Alla Della 2013). In this neighbourhood, where the correlation between the slope and flood risk is negative, the households situated on ground with little slope are more affected by the rainwater stagnation, which cannot be drained off by the saturated drainage pipes.

With regard to the variables related to environmental living conditions, we see the positive effect of a certain type of environmental quality of the dwelling (except for the quality of the walls). Having a dwelling with paved floors, using a public sector waste-collection service or having access to a sewer for disposing wastewater is generally linked to a lower likelihood of becoming a flood victim during extreme rainfall events. Intuitively, we would be tempted to relate this kind of dwelling to the socio-demographic status of the household and thus to see the effect of these environmental conditions neutralised with the introduction of socioeconomic variables. However, by using the type of models we have constructed, which allow the isolation of the specific effect of one variable, all other independent variables being equal, we see the net effect of variables concerning vulnerability linked to the environmental dimension of the living conditions. Thus, the results obtained to take account of the socioeconomic dimension of vulnerability seem counterintuitive, with no effect. This applies to the standard of living index or the level of education of the head of household. There is, nevertheless, an abundance of studies showing that the poorest people are generally at greater risk of suffering flood damage (Rentschler, Salhab and Jafino 2022; de Sherbinin and Bardy 2015). However, these analyses are often carried out using an index of poverty, which makes it impossible to demonstrate the differentiated effect of the variables of the households' immediate environment. However, our results show that it is not so much the economic dimension of vulnerability, measured exclusively based on the possession of material goods for example, that is particularly linked to the climate risk but the environmental dimension of the households' living conditions. The economic, or socioeconomic, status of a household does not allow any assumptions about the environmental living conditions, as has been shown in other contexts with regard to other types of risk (Dos Santos, Peumi and Soura 2019). This is an important result to take into account in adapting responses to future climate risks, notably with regard to the sustainable development of towns in Africa, prioritising the environmental dimension of the living conditions.

Some explanation is required regarding the highly counterintuitive effect concerning wooden walls. As stated above, 91 per cent of these households live in the wealthiest neighbourhood of Cocody. We hypothesise, on the basis of our field investigations, that part of the explanation for this result simply is a sampling artefact: the survey was carried out a few months after a very extreme event (on 18 and 19 June 2018) when a certain number of very poor inhabitants were expelled from the zones at risk. The dwellings with wooden walls at the time of the survey and still resident in this neighbourhood were located in areas that are far away from the centre, which lies alongside the main rainwater-drainage system (results not shown).

Our results show, nevertheless, that it would appear that the marginal social groups are less vulnerable: living in environmental conditions that are very precarious or, on the contrary, very sustainable, would offer protection against the risk of being affected by flooding. More in-depth investigations would be required for a better understanding of this finding.

Finally, in the results presented, we observe that the effects of some socio-demographic variables measured at the scale of the household are fairly consistent with the scientific literature on social vulnerability to extreme climatic events. These variables generally concern certain forms of social inequality (Campion and

Venzke 2013; Cannon 2010; Cutter, Boruff and Shirley 2003). Notably, a literature review highlights how a set of socio-demographic variables, in particular gender inequalities, are critical factors of social vulnerability to flooding (Rufat et al. 2015). Thus, our results regarding gender are consistent with the literature in general that has shown how the gender variable is an important factor of social vulnerability to flooding. Households headed by a woman may have less resources and less independence, and are thus less able to adopt measures of prevention and/or adaptation (Mukuna 2015; Morrow 1999; de Sherbinin and Bardy 2015). Soares and colleagues (2012) even interpret gender as one of the key factors of social vulnerability. Our results, nevertheless, contrast with other results obtained in a case study of the capital of Burkina Faso, where the authors were unable to explain why women seemed to be less vulnerable to the risk of losing their dwelling in an informal neighbourhood of the town after an extreme rainfall event (Dos Santos, Peumi and Soura 2019). Indeed, the variable that requires explanation was not the same as in the present study (losing one's dwelling because it was completely destroyed by a single extreme rainfall event versus, in the present case, having suffered at least one damage following an extreme rainfall event over ten years). This shows the importance of how the concept of flood victim or sufferer from flood damage after an extreme climatic event is operationalised: the measurement of the phenomenon might have a significant incidence on the effect of the explanatory variables concerning vulnerability, included in the statistical model.

The composition of the household, measured by its size, is a second important social variable in our results. The largest families are more vulnerable of becoming a flood victim, which is consistent with similar studies about other geogrpahical contexts (Ajibade, McBean and Bezner-Kerr 2013). These authors have shown how, at Lagos in Nigeria, the sex of the head of household has a marked effect when in interaction with other social factors, such as the family structure.

The limitations of the present research are related, above all, to the sample size. The limited sample size did not enable us to go very far in seeking contextual effects, ruling out, for example, a proper multi-level analysis. The use of the cluster option, available with the Stata software, nevertheless enabled us to statistically compensate for this concern and provide a much more robust interpretation of the odds ratios. Similarly, the size of the sample in each neighbourhood made it difficult to provide analyses by neighbourhood, which would have enabled us to obtain results specific to each neighbourhood. Nevertheless, the integration of the neighbourhood variable made it possible to consider the explained part of the phenomenon specific to each neighbourhood.

Despite these limitations, the results obtained are robust and contribute to the definition of the conceptual and analytical elements considered essential in theories for assessing vulnerability to climate change by analysis of the differentials. They also prove the richness of combining different approaches to understand the physical, environmental and social vulnerabilities, allowing the construction of a systemic and holistic analytical framework (Cutter, Boruff and Shirley 2003).

Conclusion

In view of the climate forecasts and the slowness with which states are acting to tackle global warming, the extreme meteorological phenomena resulting from climate change are likely to amplify the multiple challenges facing African city dwellers (IPCC 2022), in particular the most vulnerable of them (Simon and Leck 2015). In this context, adaptation is undoubtedly the key to the resilience to climate change in the African towns of the present and the future. The implementation of policies for sustainable urban flood-risk management requires that public resources are dedicated to actions to protect the most vulnerable groups and the areas most exposed to these hazards. It is thus of primary importance to understand the social and environmental factors of vulnerability, considering the context and the scale of various independent variables (Turner et al. 2003). In this regard, the scholarly contribution of the present article is threefold. On the one hand, the empirical results show that the vulnerability of populations to the risk of extreme rainfall should be analysed both concerning the physical characteristics specific to the households – that is, their living conditions – and their environmental and socio-demographic dimensions. Our analysis reinforces the idea that the leading cause of disaster is not hazards. In sub-Saharan Africa, urban disasters triggered by climate extremes amplify urban inequalities, given the role played by variables related to socio-environmental vulnerability as determinant factors. The multidimensional nature of vulnerability at the household level must be a challenge to public authorities in post-disaster management.

On the other hand, the detailed analysis of the socio-environmental characteristics measured at a fine scale (household level) offers new methodological perspectives for assessing social vulnerability and calls for advocacy for more data at this scale.

Finally, these results reaffirm the necessity of adopting an interdisciplinary approach to understand better the complexity of the phenomenon of vulnerabilities to climate change and thus contribute more sustainably to the adaptation of African towns in the face of these hazards. This interdisciplinary approach must respect the rules of disciplinary cultures: choosing to survey households that are not affected by the phenomenon observed is a classic approach in population sciences, unlike earth sciences, which exclusively focus on the area affected by the hazard. However, the former allowed distinguishing differentials and thus understanding the characteristics of the populations most vulnerable to flooding.

Acknowledgements

This project was funded by the Education and Research Ministry of Côte d'Ivoire, as part of the Debt Reduction-Development Contracts (C2Ds) managed by IRD (French National Research Institute for Sustainable Development) – Grant: 5768A1-PEV. We would like to thank these two institutions.

References

Ajibade, I. and G. McBean. 2014. 'Climate extremes and housing rights: A political ecology of impacts, early warning and adaptation constraints in Lagos slum communities'. *Geoforum* **55**: 76–86. https://doi.org/10.1016/j.geoforum.2014.05.005.

Ajibade, I., G. McBean and R. Bezner-Kerr. 2013. 'Urban flooding in Lagos, Nigeria: Patterns of vulnerability and resilience among women'. *Global Environmental Change* **23** (6): 1714–1725. https://doi.org/10.1016/j.gloenvcha.2013.08.009.

Alla Della, A. 2013. Les risques naturels dans l'agglomération d'Abidjan (Côte d'Ivoire). PhD Thesis, Université Félix Houphouët-Boigny.

Ashraf, M.E. 2012. 'Weighted normalized risk factor for floods risk assessment'. *Ain Shams Engineering Journal* **3** (4): 327–332. https://doi.org/10.1016/j.asej.2012.04.001.

Attoumane, A., S. Dos Santos, M. Kacou, A.D. André, A.W. Karamoko, L. Seguis and E.-P. Zahiri. 2022. 'Individual perceptions on rainfall variations versus precipitation trends from satellite data: An interdisciplinary approach in two socio-economically and topographically contrasted districts in Abidjan, Côte d'Ivoire'. *International Journal of Disaster Risk Reduction* **81**: 103285. https://doi.org/10.1016/j.ijdrr.2022.103285.

Becerra, S. 2012. 'Vulnérabilité, risques et environnement: l'itinéraire chaotique d'un paradigme sociologique contemporain'. *VertigO: La revue électronique en sciences de l'environnement* **12** (1). https://doi.org/10.4000/vertigo.11988.

Bigi, V., E. Comino, M. Fontana, A. Pezzoli and M. Rosso. 2021. 'Flood vulnerability analysis in urban context: A socioeconomic sub-indicators overview'. *Climate* **9** (1): 12. https://doi.org/10.3390/cli9010012.

Birkmann, J. and B. Wisner. 2006. *Measuring the Un-Measurable: The Challenge of Vulnerability*. SOURCE: Studies of the University: Reseach, Counsel, Education. Bonn: UNU Institute for Environment and Human Security. https://www.fao.org/fileadmin/user_upload/fsn/docs/Source_5_published.pdf (accessed 9 Jun. 2023).

Blaikie, P.M., T. Cannon, B. Wisner and I. Davis. 2004. *At Risk: Natural Hazards, People's Vulnerability and Disasters*. London: Routledge. https://doi.org/10.4324/9780203974575.

Bohle, H.-G. 2007. *Living with Vulnerability: Livelihoods and Human Security in Risky Environments*. InterSecTions: Interdisciplinary Security Connections. Bonn: UNU Institute for Environment and Human Security. http://collections.unu.edu/eserv/UNU:1860/pdf3858.pdf (accessed 9 Jun. 2023).

Campion, B.B. and J.-F. Venzke. 2013. 'Rainfall variability, floods and adaptations of the urban poor to flooding in Kumasi, Ghana'. *Natural Hazards* **65** (3): 1895–1911. https://doi.org/10.1007/s11069-012-0452-6.

Cannon, T. 2010. 'Gender and climate hazards in Bangladesh'. *Gender and Development* **10** (2): 45–50. https://doi.org/10.1080/13552070215906.

Cutter, S.L., B.J. Boruff and W.L. Shirley. 2003. 'Social vulnerability to environmental hazards'. *Social Science Quarterly* **84** (2): 242–261. https://doi.org/10.1111/1540-6237.8402002.

Cutter, S.L., C.T. Emrich, D.P. Morath and C.M. Dunning. 2013. 'Integrating social vulnerability into federal flood risk management planning'. *Journal of Flood Risk Management* 6 (4): 332–344. https://doi.org/10.1111/jfr3.12018.

de Sherbinin, A. and G. Bardy. 2015. 'Social vulnerability to floods in two coastal megacities: New York City and Mumbai'. *Vienna Yearbook of Population Research* 13: 131–165. https://doi.org/10.1553/populationyearbook2015s131.

Dos Santos, S., J.-P. Peumi and A. Soura. 2019. 'Risk factors of becoming a disaster victim: The flood of September 1st, 2009, in Ouagadougou (Burkina Faso)'. *Habitat International* 86: 81–90. https://doi.org/10.1016/j.habitatint.2019.03.005.

Douglas, I.A., M.M. Kurshid, Y. Mcdonnell, L. McLean and J. Campbell. 2008. 'Unjust waters: Climate change, flooding and the urban poor in Africa'. *Environment and Urbanization* 20 (1): 187–205. https://doi.org/10.1177/0956247808089156.

Douglas, M. and A. Wildavsky. 1982. *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*. Berkeley: University of California Press. https://doi.org/10.1525/9780520907393.

INS 2022. *Estimation provisoire de la population dans les quartiers des communes du district d'Abidjan – Recensement de population 2021*. Abidjan: National Institute of Statistics.

IPCC 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability – Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Kabisch, S., N. Jean-Baptiste, R. John and W.J. Kombe. 2015. 'Assessing social vulnerability of households and communities in flood prone urban areas'. In S. Pauleit, A. Coly, S. Fohlmeister, P. Gasparini, G. Jørgensen, S. Kabisch, W.J. Kombe, S. Lindley, I. Simonis, K. Yeshitela (eds), *Urban Vulnerability and Climate Change in Africa*, pp. 197–228. Cham: Springer. https://doi.org/10.1007/978-3-319-03982-4_6.

Kit, O., M. Lüdeke and D. Reckien. 2011. 'Assessment of climate change-induced vulnerability to floods in Hyderabad, India, using remote sensing data'. In K. Otto-Zimmermann (ed.), *Resilient Cities:*

Cities and Adaptation to Climate Change – Proceedings of the Global Forum 2010, pp. 35–44. Vol. 1, Local Sustainability. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-0785-6_4.

Koks, E.E., B. Jongman, T.G. Husby and W.J.W. Botzen. 2015. 'Combining hazard, exposure and social vulnerability to provide lessons for flood risk management'. *Environmental Science & Policy* **47**: 42–52. https://doi.org/10.1016/j.envsci.2014.10.013.

Kouamé, P.K., G. Fokou, A.J. Koffi, A. Sani, B. Bonfoh and K. Dongo. 2022. 'Assessing institutional stakeholders' perception and limitations on coping strategies in flooding risk management in West Africa'. *International Journal of Environmental Research and Public Health* **19** (11). https://doi.org/10.3390/ijerph19116933.

Kouassi, A., R. Nassa, K. Yao, K. Kouame and J. Biemi. 2018. 'Modélisation statistique des pluies maximales annuelles dans le district d'Abidjan (sud de la Côte d'Ivoire)'. *Revue des sciences de l'eau* **31** (2): 147–160. https://doi.org/10.7202/1051697ar.

Lebel, T., F. Delclaux, L. Le Barbé and J. Polcher. 2000. 'From GCM *scales to hydrological scales: Rainfall variability in West Africa'. Stochastic Environmental Research and Risk Assessment* **14** (4): 275–295. https://doi.org/10.1007/s004770000050.

Léone, F. and F. Vinet. 2006. 'La vulnérabilité un concept fondamental au coeur des méthodes d'évaluation des risques naturels'. In F. Léone and F. Vinet (eds), *La vulnérabilité des sociétés et des territoires face aux menaces naturelles: Analyses géographiques*, pp. 9–25. Montpellier: Les Presses universitaires de la Méditerranée (PULM).

McCarthy, M.P., M.J. Best and R.A. Betts. 2010. 'Climate change in cities due to global warming and urban effects'. *Geophysical Research Letters* **37** (9): L09705. https://doi.org/10.1029/2010GL042845.

Morrow, B.H. 1999. 'Identifying and mapping community vulnerability'. *Disasters* **23** (1): 1–18. https://doi.org/10.1111/1467-7717.00102.

Mukuna, T.E. 2015. 'Vulnerability analysis of the gender-differentiated impact of flooding in Budalangi Flood Plains, Kenya'. *Journal of Emerging Trends in Educational Research and Policy Studies* **6** (2): 201–216.

O'Brien, K., S. Eriksen, L.P. Nygaard and A.N.E. Schjolden. 2007. 'Why different interpretations of vulnerability matter in climate change discourses'. *Climate Policy* **7** (1): 73–88. https://doi.org/10.1080/14693062.2007.9685639.

OCHA 2014. 'Côte d'Ivoire: Zones à risques d'inondations et de choléra'. United Nations Office for the Coordination of Humanitarian Affairs. https://reliefweb.int/report/c-te-divoire/c-te-d-ivoire-zones-risques-d-inondations-et-de-chol-ra-juin-2014 (accessed 9 Jun. 2023).

PNUD 2013. *Diagnostics et plans d'amélioration des quartiers précaires des 13 communes du district d'Abidjan*. Abdjan: Programme des Nations unies pour le Développement.

PNUD 2021. *Rapport sur le développement humain 2020: Note d'information à l'intention des pays concernant le rapport sur le développement humain 2020 – Côte d›Ivoire*. Abidjan: Programme des Nations unies pour le Développement. https://hdr.undp.org/sites/default/files/Country-Profiles/fr/CIV.pdf (accessed 9 Jun. 2023).

Reckien, D., F. Creutzig, B. Fernandez, S. Lwasa, M. Tovar-Restrepo, D. McEvoy and D. Satterthwaite. 2017. 'Climate change, equity and the Sustainable Development Goals: An urban perspective '. *Environment & Urbanization* **29** (1): 159–182. https://doi.org/10.1177/0956247816677778.

Reckien, D., M. Wildenberg and M. Bachhofer. 2013. 'Subjective realities of climate change: How mental maps of impacts deliver socially sensible adaptation options'. *Sustainability Science* **8** (2): 159–172. https://doi.org/10.1007/s11625-012-0179-z.

Rentschler, J., M. Salhab and B.A. Jafino. 2022. 'Flood exposure and poverty in 188 countries'. *Nature Communications* **13** (1): 3527. https://doi.org/10.1038/s41467-022-30727-4.

Rufat, S., E. Tate, C.G. Burton and A.S. Maroof. 2015. 'Social vulnerability to floods: Review of case studies and implications for measurement'. *International Journal of Disaster Risk Reduction* **14** (4): 470–486. https://doi.org/https://doi.org/10.1016/j.ijdrr.2015.09.013.

Simon, D. and H. Leck. 2015. 'Understanding climate adaptation and transformation challenges in African cities'. *Current Opinion in Environmental Sustainability* **13**: 109–116. https://doi.org/https://doi.org/10.1016/j.cosust.2015.03.003.

Soares, M.B., A.S. Gagnon and R.M. Doherty. 2012. 'Conceptual elements of climate change vulnerability assessments'. *International Journal of Climate Change Strategies and Management* **4** (1): 6–35. https://doi.org/10.1108/17568691211200191.

Turner, B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, J.X. Kasperson, A. Luers, M.L. Martello, C. Polsky, A. Pulsipher and A. Schiller. 2003. 'A framework for vulnerability analysis in sustainability science'. *Proceedings of the National Academy of Sciences* **100** (14): 8074–8079. https://doi.org/10.1073/pnas.1231335100.

UNDESA 2018. *World Urbanization Prospects: The 2018 Revision*. New York: United Nations Department of Social and Economic Affairs. https://population.un.org/wup/ (accessed 9 Jun. 2023).

UNISDR 2015. *The Human Cost of Weather Related Disasters 1995–2015*. Geneva: United Nations Office for Disaster Risk Reduction. https://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf (accessed 9 Jun. 2023).

White, G.F. 1946. Human adjustment to floods. PhD Thesis, University of Chicago.

Wilby, R.L. 2007. 'A review of climate change impacts on the built environment'. *Built Environment Journal* **33** (1): 31–45. https://doi.org/10.2148/benv.33.1.31.

Zahiri, E.-P., I. Bamba, A.M. Famien, A.K. Koffi and A.D. Ochou. 2016. 'Mesoscale extreme rainfall events in West Africa: The cases of Niamey (Niger) and the Upper Ouémé Valley (Benin)'. *Weather and Climate Extremes* **13**: 15–34. https://doi.org/10.1016/j.wace.2016.05.001.