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Introduction

1 Since the International Decade for Natural Disaster Reduction -1990 to 1999- (UNDP, 2004), the issue of populations' vulnerability has remained at the heart of the international community's preoccupations (Kouassi et al., 2010; Lhomme, Laganier, Diab, Serre, 2013). Indeed, the recurrence of natural disasters and their impact have driven states to take action to help populations to adapt and reduce risks. Worldwide, "*in 2015, natural disasters led to economic losses of 92 billion dollars, and average losses of disasters were estimated at over 300 billion dollars per year*" (Hallegate, Vogt-Schilb, Rozenberg, 2016). According to CRED's EM-DAT database (CRED, 2020), flooding constitutes the primary risk of natural disasters in the world when one considers the number of events and individuals affected. To that end, many researchers throughout the world have taken on the study of natural disasters in order to understand the causes and to identify objectively the consequences and their inadequate management (Hostache, 2007; Karambiri, Tazen, Traore, Bologo/Traore, Coulibaly, 2015; Lhomme et al., 2013; Ntajal, Lamptey, Mahamadou, Nyarko, 2017; Pradhan, 2010; Van Westen,

2013). In most of the work done on risk disasters, the concept of vulnerability remains a major issue. These works generally show that vulnerability results from intrinsic characteristics of populations, their potential exposure to a hazard, their awareness linked to the exposure (Burton, Kates, White, 1993; Cutter, 1996), the capacity for adaptation which varies from one individual to another (Birkmann, 2007; Buckle, Marsh, Smale, 2001; Turner et al., 2003), the spatial occupancy (Cardona, 2004; Cutter, Boruff, Shirley, 2003) and the characteristics of the hazard (Wilhelmi, Morss, 2013). It comprises two dimensions: biophysical vulnerability related to hazard exposure and social vulnerability related to society (Cutter et al., 2003; Reghezza, 2006).

2 Social vulnerability is a territorially rooted notion, central to risk analysis in the urban environment (Adger, 2006; Quenault, 2015). It denotes the incapacity of a society to anticipate a hazard, to cope with an emergency, to adapt its behaviour during a crisis and to reconstruct itself (Wisner, Blaikie, Cannon, Davis, 2003). It depends upon social factors such as demographic characteristics, discriminations, social inequality, imbalance of power (Becerra, 2012; Birkmann, Wisner, 2006) as well as institutional, economic, cultural, historical and political factors (Meschinet de Richemond, Reghezza, 2010). To these aspects, one can add health (Jonkman, Kelman, 2005; Ruin, 2007; Vinet, Boissier, Defossez, 2011), adaptive capacity (Lallau, Rousseau, 2009; Pelling, 2003), risk perception (Becerra et al., 2013; Bonnet, 2002; Kellens, Zaalberg, Neutens, Vanneuville, De Maeyer, 2011; Ruin, Lutoff, 2004), quality of life in the neighbourhoods and land tenure (Rufat, Tate, Burton, Maroof, 2015).

3 Even if Africa is not the continent which has been the most affected by flooding globally, the impact and consequences of these disasters can prove to be devastating, putting it among the most vulnerable of continents. This is due to the considerable dependence of these countries on natural resources, to social and biophysical vulnerability and to a relatively limited adaptive capacity. These findings are all the more alarming in the countries of West Africa, which are already confronted with a generalized impoverishment and have, for two decades, been victims of flooding practically every year. This situation can be explained not only by extreme rainfall but by transformations in urban spaces, in their rhythm, form and governance (Hangnon, De Longueville, Ozer, 2015).

4 Ouagadougou, the capital of Burkina Faso, is an example of a West African crossroads city whose economy has been badly affected by the consequences of natural disasters. It is an urban centre that has experienced an increase in the frequency of flooding, principally linked to rain runoff overloads and extreme storm events. The major floods of 2009, 2015, 2016 and 2018 caused considerable material damage and loss of human life (Pictures 1 and 2). They revealed certain risky collective behaviours in the post-disaster period, such as the resettlement of populations in flood-prone areas after the 2009 floods (Essone Nkoghe, 2012; Hangnon, Bonnet, Amalric, Nikiema, 2018). They also highlighted the city's exposure and great vulnerability of its populations to flooding in particular.

Picture 1: The city centre of Ouagadougou flooded on 1st September 2009

credit: Ahmed OUOBA/ AFP

Picture 2: Collapsed house in the undeveloped area of Ouagadougou during the 2015 floods

credit: http://news.aouaga.com

5 Today, although flood risk reduction measures have been implemented after the major floods mentioned above, Ouagadougou is still subject to flooding. The populations also still live in areas declared flood-prone, unbuildable or likely to be flooded and are still strongly impacted by these phenomena. To understand this situation, which incidentally is not specific to the city of Ouagadougou, several authors have worked on the concept of vulnerability and the means to measure it at the local or global level (Adger, Brooks, Kelly, Bentham, Eriksen, 2004; Balica, Wright, van der Meulen, 2012; Cutter et al., 2003; Flanagan, Gregory, Hallisey, Heitgerd, Lewis, 2011; Karambiri et al., 2015; Tazen et al., 2019). Most of these authors agree that social factors have a strong influence on risk management and coping skills and have therefore addressed

vulnerability from a social perspective in their studies, either fully or partially. For instance, the study by Karambiri et al. (2015) assessed the vulnerability of Ouagadougou by determining, among other things, the flood social vulnerability index (FVI_{social}). This index, inspired by the work of Balica et al. (2012), is based on the aggregation of social indicators from censuses or reports by adding or multiplying them in some way. Another social vulnerability index that is widely used in the literature is the SoVI index developed by Cutter (2003). This index is also based on the aggregation of variables derived from censuses but this aggregation process is performed using principal component analysis.

6 All these studies have the common feature of seeking to measure the absolute vulnerability of a given territory by aggregating several variables using various techniques and relying essentially on data from censuses or reports. Overall, this type of approach using vulnerability indexes raises a number of problems. A major limitation noted by Rufat (2013) is that in these studies "*vulnerability indicators are added together or multiplied in different ways by different authors without taking their diversity and interaction into account*". Moreover, these indexes strongly depend on the initial choice of variables (Tate, 2012). Also, the latter are subject to collinearity bias (Rufat, 2013). The result is an arbitrary, subjective and incomplete presentation of vulnerability levels with indexes that tend to oversimplify the complexity of the concept and erase its heterogeneity at the local level. Because of all these limitations and the validity problems noted by some authors (Rufat, Tate, Emrich, Antolini, 2019; Schmidtlein, Deutsch, Piegorsch, Cutter, 2008; Spielman et al., 2020), this approach to vulnerability remains problematic for operational use by managers.

7 So, how can we assess the vulnerability of populations in this context in order to better adapt prevention measures? To answer this question, Rufat (2013) proposed shifting the focus from measuring absolute vulnerability, which would be too complex to understand, to relative vulnerability.

8 Relative vulnerability is related to understanding the processes that make or break vulnerability in a given locality and is more operational than the absolute measure of vulnerability. In other words, analysing relative vulnerability would serve to answer certain operational questions. Which are the most vulnerable populations in a given locality, and why are they vulnerable? Are there aggravating factors related to where they live? Although these questions are central to flood management in the city of Ouagadougou, they have not been given much thought in the city, as the application of relative vulnerability analysis techniques has focused on other regions. It is to compensate for this shortcoming that our study was envisaged.

Presentation of the study zone

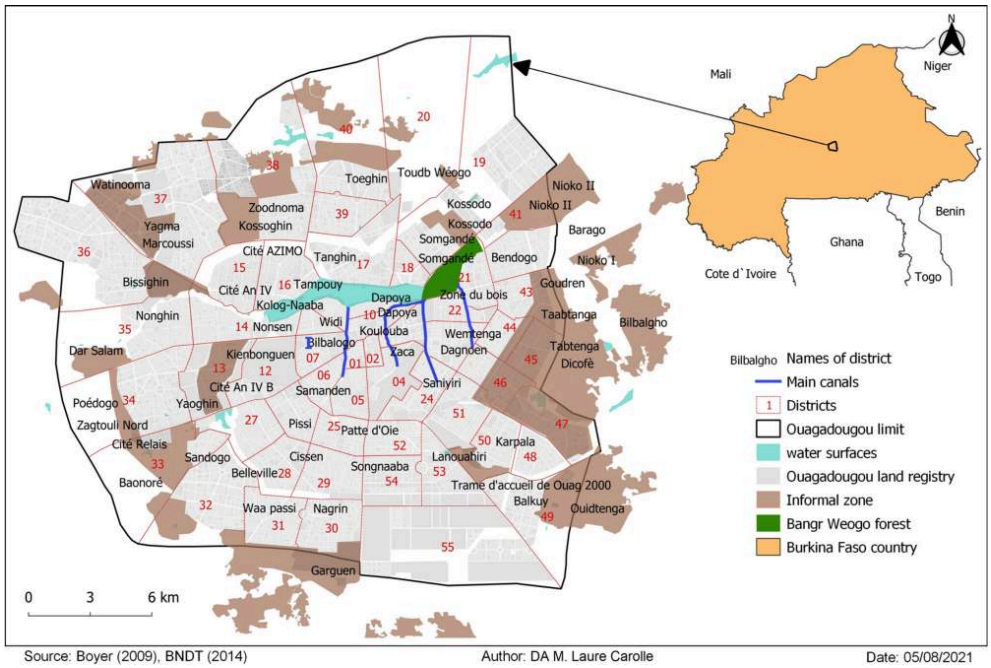
9 The city of Ouagadougou, located in the heart of West Africa, was chosen as the study area for the implementation of the Rufat approach because of its high exposure to flooding due to its characteristics. Comprising 55 sectors at an average altitude of 310 m, the urban municipality of Ouagadougou extends over 518 km² and has a flat, gently sloping terrain (Picture 3). The morphology of the town is monotonous with gentle slopes of 0.6 to 1% (Kêdowidé, Sedogo, Cissé, 2010). These features lead either to rainwater stagnation or ingress according to the nature of the ground.

Picture 3: Ouagadougou seen from the top of a building: a city with flat terrain

Credit: DA M. Laure Carolle

10 The city of Ouagadougou is drained by four principal canals resulting from development of topographical depressions (Figure 1). The hydrographic network, moreover, is made up of watercourses operating intermittently, and of four intra-urban dams. Three of these dams are inter-connected and numbered 1 to 3 from upstream to downstream. They discharge their water into the River Massili crossing the gazetted Bagr-Wéogo forest, the natural outlet of the city's rainwater.

Figure 1: Presentation of the study area



Source: Boyer (2009), BNDT (2014) Author: DA M. Laure Carolle Date: 05/08/2021

11 Several works based on the analysis of press-reported stories have reported an increase in the frequency of floods over the past 30 years in Burkina Faso in general (Taylor, Traoré/Bologo, Tazen, 2019) and in the capital city of Ouagadougou in particular (Hangnon et al., 2018). Tazen (2019) has noted, for example, an average of five floods per year in the city since the 2000s, with significant impacts on people and property.

12 The problem of flooding is therefore a major issue for the city of Ouagadougou, particularly for the most vulnerable populations. It is important for decision-makers, beyond the aspects related to the hazard, to understand the processes of social vulnerability in order to provide solutions adapted to the context of Ouagadougou. This is the goal of our article.

Material and methods

13 The analysis of the relative social vulnerability of the inhabitants of Ouagadougou was carried out in this article by adapting the methodology proposed by Rufat (2013)[1]. Survey data were used in the process instead of the census or report data used in the Rufat method. Indeed, the census data present several constraints that are particularly important in the context of our study.

14 Census or report data are usually incomplete or on a scale that is inappropriate for urban studies, especially in West Africa. Moreover, when they are available, these data are generally from different sources that may have collected and published them at different times, which may compromise the selection of variables. Indeed, these variables may not correspond to social indicators from comparable periods.

15 Thus, in order to identify the socio-spatial vulnerability profiles of the inhabitants of Ouagadougou based on up-to-date data, a survey using stratified random sampling was conducted from Mars to April 2017 in the city of Ouagadougou by a dozen trained interviewers. This survey allowed us to interview, on the basis of a questionnaire[2] (Appendix F), a sample of 2137[3] persons, each belonging to a household that it represented. The rule for selecting households to be surveyed was to cross two perpendicular streets, leaving at least 200 metres between each house surveyed. Interviews with neighbours were not allowed.

16 The questions were asked of a single representative of the household, namely the head of the family or another member of the household of over 18 years of age living for at least six months in the household. Responses from women were encouraged. During the survey, nine respondents did not meet the selection criteria or did not agree to the survey and were therefore excluded from the analyses. These individuals were not included in the 2137 respondents who all met the selection criteria.

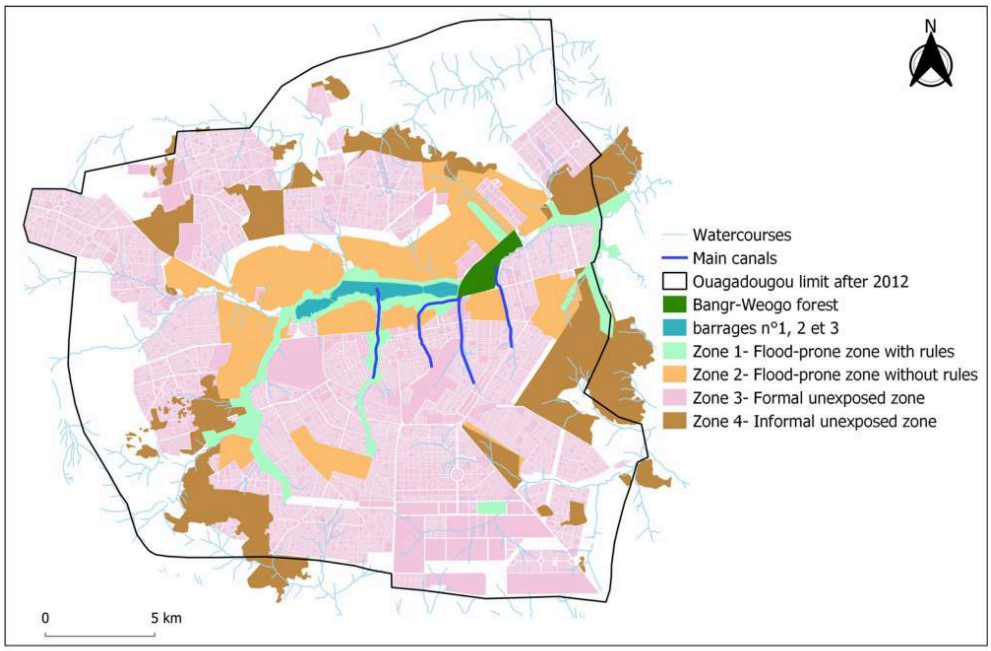
17 The survey sampling was stratified according to four zones (Figure 2), each belonging to a group qualified as exposed or not exposed to floods. The sampling was done so that each group had approximately the same population ratio (46.56% for the exposed group and 53.44% for the unexposed group). The zones, numbered from 1 to 4, were determined according to their status in urban planning[4]. Exposure of a zone to flooding is defined in this study by an identification by the regulation[5], or by the print media (or by both). All the zones, both formal[6] and informal, were surveyed. The exposed zones of the city (zones 1 and 2) are located around dams 1, 2 and 3 of the city and to a lesser degree on the outskirts (Figure 2).

18 The number of households to be surveyed in each zone was set to best approximate the ratio of area in each zone to group membership (Table 1), to be spatially representative.

Table 1: Identification of the survey areas

Groups	Area by group (km²)	Respondents per group	Zones	Area per zone (km²)	% of area by zone	Respondents per zone	% respondents per zone
Exposed	83.5	995	Zone 1	22.49	26.93%	212	21.30%
			Zone 2	61.01	73.06%	783	78.69%
Non exposed	198.28	1142	Zone 3	111.43	56.20%	643	56.30%
			Zone 4	86.85	43.080%	499	43.69%

Figure 2: Presentation of the study zones according to the four zones of the survey



19 Analysing social vulnerability requires taking into account its multidimensional basis. With this in mind, the survey questionnaire was developed taking into account the main aspects that can influence social vulnerability. These were about:

- -inhabitants' socioeconomic characteristics (household's asset for wealth level, education, etc.)
- -knowledge about the flood phenomena (causes, awareness of exposure to risk, etc.)
- -experience of floods, damage and ability to recover
- -knowledge of prevention and safety regulations
- -potential behaviours when a flood occurs

20 In total, 84 variables, mainly qualitative, considered as drivers for social vulnerability, were gathered to establish socio-spatial vulnerability profiles. The data processing consisted of a statistical analysis in several stages:

Calculation of a wealth index: principal component analysis (PCA)

21 The wealth index is a composite measure of a household's standard. It was used to understand the socio-economic status of households through a number of variables related to the goods they possess (number of television sets, refrigerators etc.). This is an interesting driver that has a definite impact on the level of social vulnerability of a territory (Fischer, Chhatre, 2016). The method proposed by the World Food Programme (2017) to establish this index consists, with SPSS software, in assigning a standardized weight or score to each selected quantitative variable through a principal component analysis (PCA). Individuals are then classified according to their score. The sample is finally divided into population quintiles. Each quintile corresponds with an economic well-being level from 1 (for the poorest) to 5 (for the richest) (INSD, 2015). We thus obtained a qualitative variable with 5 modalities which can be used thereafter to determine the profiles of vulnerability.

Highlighting of redundancies: Chi2 and Cramer's V [7]

22 They are calculated to establish the correlations between variables to determine the significant variables, with the least possible redundancy, in order to establish the profiles. The analysis of these correlations and their strength made it possible to eliminate the super-linked variables in order to make the factor analysis more robust (Habib Bawa, 2018; Ritschard, Zighed, Nicoloyannis, 2001; Yabi, Sossou, Akindele, Balogoun, Ogouwale, 2019). According to Rufat et al. (2019), "*this process limited collinearity, prevented implicit weighting, strengthened statistical power and preserved a balance between the different dimensions of vulnerability*". This stage led to the adoption of 13 variables for the remainder of analyses (Table 2).

Table 2: Variables selected after correlation analysis

Variables	Categories	Respondents	%	Description
Wealth_index	1	427	19.98	Wealth level (1 for poor and 5 for rich)
	2	428	20.03	
	3	427	19.98	
	4	429	20.07	
	5	426	19.93	
Education	never_school	883	41.32	Level of education (never_school = never been schooled)
	literate	170	7.96	
	primary	375	17.55	
	secondary	436	20.40	

	university	273	12.77	
Flood_Time	2h	1039	48.62	Minimum length of time during which the water remains to call it a flood
	½ d (1/2 day)	735	34.39	
	+1day (several days)	363	16.99	
Norm_flood	normal	236	11.04	Qualifier of a flood: normal? Not normal?
	abnormal	1901	88.96	
Resp_state	Yes	1623	75.95	Responsibility of the state
	No	514	24.05	
C_urbaniz	Yes	1294	60.55	Urbanization in flood-prone zone causes flooding
	No	843	39.45	
Percep_zone	floodable/ forbidden	166	7.77	Perception on the residential area
	None	1553	72.67	
	Idk	418	19.56	
Warning	Yes	1738	81.33	Knowledge of precautions to be taken in the event of flooding
	No	243	11.37	
	Idk	156	7.30	
Cp_instruction	Yes	319	14.93	Instructions from civil protection
	No	1384	64.76	
	Idk	434	20.31	
home_digging	Yes	1253	58.63	Digging to let water through
	No	884	41.37	
home_clean	Yes	327	15.30	Clear gutters to let water through
	No	1810	84.70	
Stay_out	Yes	646	30.23	Stay outside if a flood surprises one outdoors
	No	1491	69.77	
See_out	Yes	142	6.64	Go and see the flood

	No	1995	93.36	

*Idk: I don't know

Looking for profile characteristics: Multiple correspondence analysis (MCA)

23 Since all the selected variables were qualitative, we opted for a multiple correspondence analysis as factor analysis before the clustering method. MCA is a descriptive statistical technique which also aims to summarize and visualize a table of data containing more than two qualitative variables (Renisio, Sinthon, 2014). The objective is to identify groups of people with a similar profile and to show the associations between variables and modalities. To take into account the sensitivity of the MCA to low numbers (less than 5%), we grouped the rare modalities as recommended by Husson et al. (2010). The factor coordinates obtained were thus used as quantitative variables for the clustering method.

24 *Identification of clusters: Hierarchical Agglomerative Clustering (HAC)*

25 It was conducted using the R software employing the FactoMineR package in accordance with Ward's method and Euclidean distance matrix. It consists in dividing the populations into different clusters, based on the MCA results. The advantage of this technique is that the largest possible group of similar individuals can be grouped within the same cluster (cross-cluster homogeneity) and to define the most dissimilar cluster (cross-cluster heterogeneity) (Rérolle, Faisant, Telmon, Saint-Martin, 2015). Along with the inspection of the dendrogram and the analysing of statistics of inertia gain, we also determined the number of clusters retained using the Ratkowsky and Dunn indices. This number is the one that maximizes each of the indices. These indices are ranked by several studies as high performers for determining optimal number of clusters (Charrad, Ghazzali, Boiteau, Niknafs, 2014; Tian, Lemos, 2018). According to these metrics, eight clusters seem to best capture the clustering structure in the data, since they give the highest desired values (Table 3).

Table 3: Quantitative indices to determine optimal number of clusters

Number of clusters	**Indices for clustering evaluation**	
	Ratkowsky index	Dunn Index
2	0.1242	0.1135
3	0.1543	0.116
4	0.1716	0.1193
5	0.1813	0.1193
6	0.1922	0.1199
7	0.1998	0.1199
8	0.2013	0.1253

9	0.2001	0.1253
10	0.1953	0.1253

Results

Representativeness of the sample

26 The random sampling approach resulted in an overall representativeness of the urban population for different socio-demographic variables, as shown in Table 4. Indeed, the verification of the representativeness of our sample is a prerequisite for validating the results, and therefore for interpreting them. Thus, we observe that the ratios of socio-economic variables such as gender, educational level and occupation are close to the ratios found in censuses conducted by the National Institute of Statistics and Demography of Burkina Faso. We can therefore conclude that our sample is somewhat socially representative.

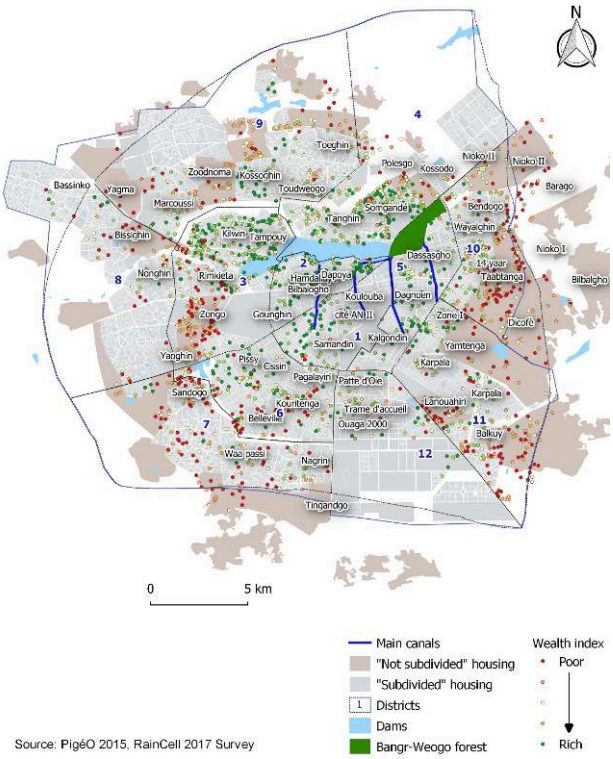
Table 4: comparison of socio-demographic characteristics of respondents with census data

Variables	**Survey results (%)**	**Census data**	
		% by variables	Source
Gender			RGPH 2020
Female	51.15	50.93	
Male	48.85	49.06	
Educational level			RGPH 2006
Never been to school	41.32	45.4	
Primary	14.55	18.8	
Secondary	20.40	24.2	
University	12.77	11.3	
Occupation			Statistical yearbook 2017
Unemployed	21.99	22.4	
In employment	78.01	77.6	

Socio-economic profile of populations and spatial distribution of individuals

27 The socio-economic profiles determined by the PCA are presented in figure 3. These profiles are representative of Ouagadougou and show the spatial distribution of the level of economic well-being in the city.

Figure 3: Distribution of the population surveyed according to the wealth index



28 Determining the wealth index of the people surveyed confirms that the majority of less well-off populations live in the outlying areas (Figure 3). Their presence can be explained by the level of land speculation in Ouagadougou and the difficulty for households to have access to parcels and dwelling places in the city-centre because of high prices.

29 Two types of proprietors rub shoulders in the informal settlements (Robineau, 2014). On the one hand, there are families in precarious financial situations settling in an informal zone (which has not been divided into lots) because it is easier to acquire a parcel there for a lower price and these areas offer the advantage of access to the city's amenities (e.g. work etc.). These families' houses are generally built using precarious materials (Picture 4). On the other hand, middle-class families generally with lower resources than families in the city centre, however, often acquire an "alibi parcel" in the hope that one day they can benefit from a lot in a subdivided zone. In these cases, houses are built with better amenities (Picture 5).

30 Many "poor" households, therefore, settle on the outskirts of town while hoping to be able to benefit from a parcel when subdivisions take place (Boyer, Delaunay, 2009). They understand the interest of moving from an informal settlement to a property in a subdivided zone, as the value of the parcel rises considerably during the subdivision,

according to the neighbourhood, multiplying by two if not by three the price per square metre. Due to land-use speculation, it is not rare to see households sell parcels allocated to them on completion of the housing development, moving from one informal home to another in the hope of earning some money (Delaunay, Boyer, 2017).

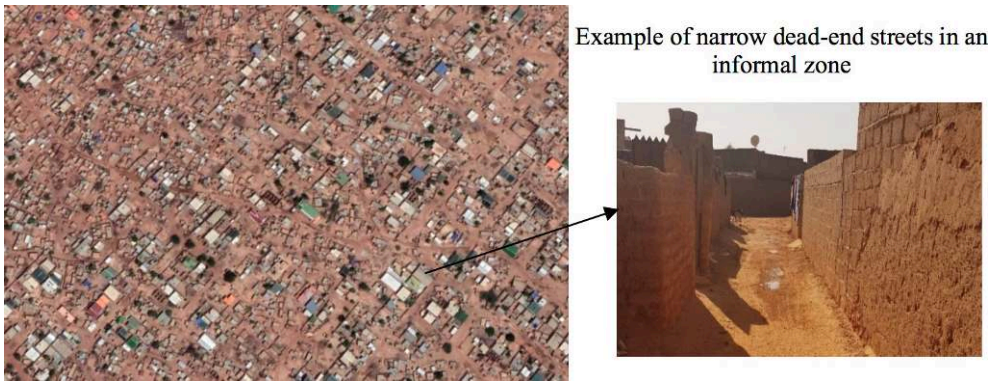
Picture 4: House built of precarious materials in the informal settlement area of Somgandé.

Picture 5 : House built in the informal settlement of Zagtouli.

31 In addition, the economic level of households, related to the locality of residence of households, has an impact on the damage they are likely to suffer in the event of a flood, but also on their ability to cope and their attitudes towards risk. The constructions using precarious materials due to low resources in the non-settled areas

and the absence of urban planning make populations more vulnerable to the risk. Picture 6 highlights the disorganization in the informal sectors with narrow lanes that do not respect any norms, which makes access by vehicle almost impossible and complicates evacuation in the event of a disaster.

Picture 6: Spatial disorganization in undeveloped areas



32 Moreover, some informal settlements such as Zongo in the west and Yaamtenga in the east (Figure 3), known as "non-lotis" or "not subdivided housing", have existed for 20 years. In these neighbourhoods lacking in basic amenities with no rainwater drainage infrastructures, a high density of the population lives in precarious conditions. The "eviction"[8] on the grounds of risk prevention in these zones is made difficult owing to the length of time households have been settled there.

33 Thus, the economic well-being of households has an impact on the spatial occupation of the city but also, as will be shown in more detail, on its social vulnerability.

Underlying factors of vulnerability

34 The multiple component factor analysis (MCA) resulted in the extraction by using the Kaizer criterion of 10 dimensions, which explained a total of 54.93% of the variance in the data set. The first and the second dimension explained 8.77% and 6.77% variability of the data, respectively. The details of eigenvalue and percentage variance explained by 10 dimensions using MCA output are provided in the supplementary information (Appendix B).

35 MCA was used in our study to understand the distribution of individuals and variables (Appendix C). Figure 4 shows the weight of different variables and categories on the first factorial plane. The first dimension is differentiated on the basis of categories of wealth index (Wealth_index= 0.48) and level of education (education= 0.42). It seemed to explain the social level of residents. Thus, this first axis produced by the analysis structures the population of the survey and distinguishes:

- poor individuals (low wealth_index =<3), who have never been to school and who do not know if their zone is at risk of flooding or not,
- and individuals who do not present these characteristics;

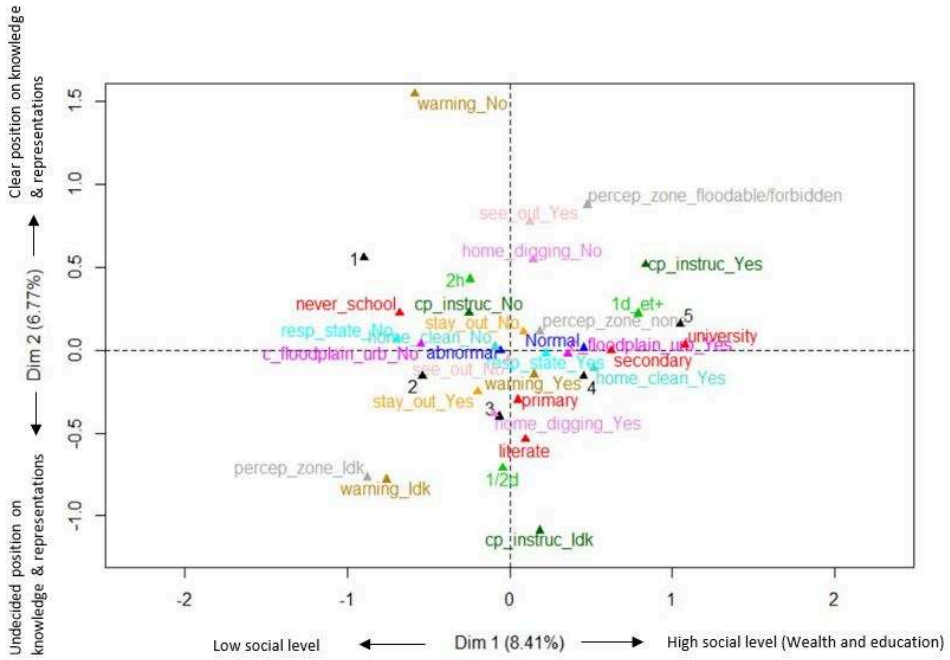
36 The second dimension opposes two aspects:

- the modalities at the bottom of the graph indicate a doubt about awareness of the instructions (on the right) and the precautions (on the left) and on perceptions of risk in the residential zone;

- and the modalities at the top of the graph, which correspond to the representation of those who have a clear position as to their knowledge of the guidelines and the risk in the residential zone.

37 This dimension is discriminated on the basis of representations (percep_zone=0.18) and knowledge of precautions (warnings=0.33) and civil protection instructions (cp_instruc= 0.31).

Figure 4: Profile of the people surveyed according to their responses on axes 1 and 2 of the MCA

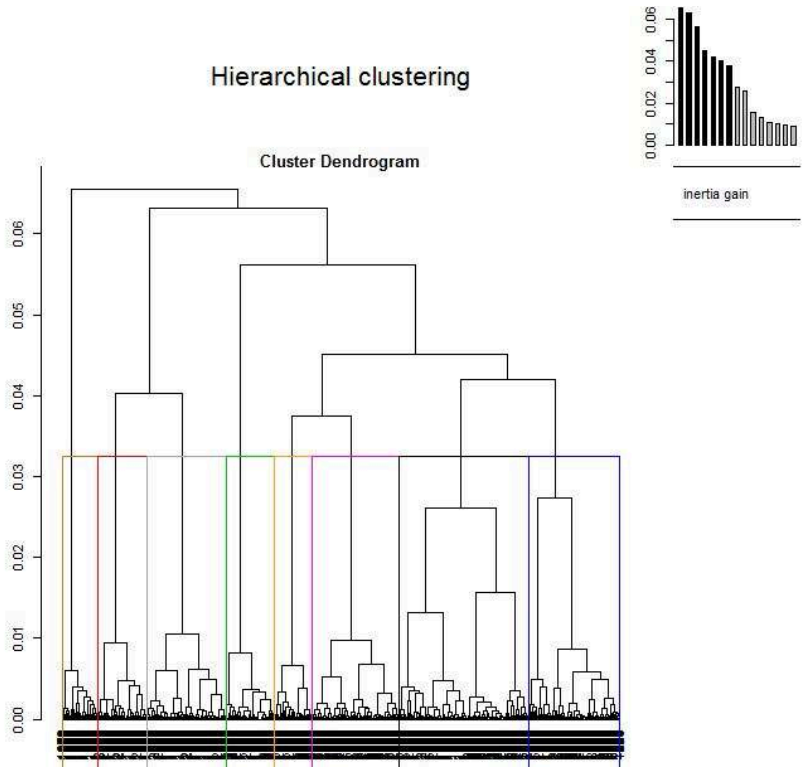


38 The factor score generated for the 10 dimensions was used as input data for cluster analysis by Hierarchical Agglomerative Clustering.

Profiles of the most vulnerable populations in the city

39 The HAC undertaken following the MCA makes it possible to highlight eight clusters with a certain diversity within each group (Figure 5).

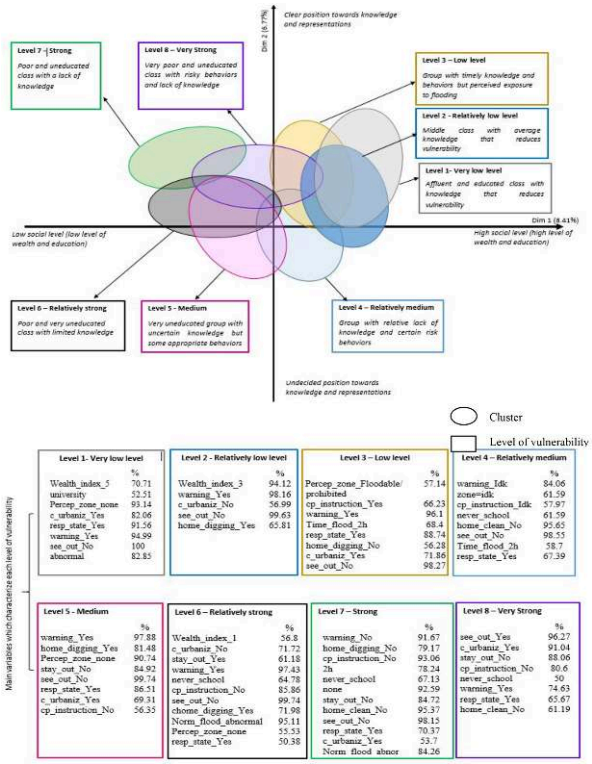
Figure 5: Dendrogram of individuals resulting from Hierarchical Agglomerative Clustering of Ouagadougou's inhabitants



40 A scale of vulnerability from one to eight, based on the interpretation of these clusters, is constructed, with level 1 the lowest level of vulnerability and 8 the highest. This scale depends on an interpretation of statistical results obtained. It is therefore at least partially subjective, despite all the efforts made. Thus, the scales revealed by this method are not comparable from one study to another, even if the approach is reproducible.

41 Figure 6 shows the distribution of the eight levels of vulnerability and summarizes the main factors that differentiate all these clusters of residents on the first factor plane. It shows that the groups are organized according to their social level as well as knowledge and representations. Details of each profile are mentioned in the different boxes.

Figure 6[9]: Distribution of the surveyed populations into eight clusters on the 1st factor plane



42 The specific characteristics of each cluster are analysed in the sub-sections below.

43 *Type 1 - vulnerability level 1.* The first group (n=18.20%) with the lowest level of vulnerability is the affluent households (wealth_index = 5), whose representatives have mostly a high level of education and a good knowledge of flood precautionary measures. They are convinced that their residential area is not subject to flooding or prohibited for construction probably because they have very rarely been flooded.

44 *Type 2 - vulnerability level 2.* The second group (n=6.46%) concerns mostly middle class households (wealth_index= 3). Their household-representatives are aware of the precautions to take, do not have risk behaviour but are ignorant of the causes of the floods.

45 *Type 3 - vulnerability level 3.* The third group (n=10.11%) concerns the households with representatives who think they live in a zone which is liable to flooding or is a prohibited area, who know the civil protection guidelines[10] and the precautions to take[11] and who are well aware of the causes of floods. They do not have any risk behaviour (going to see the flood).

46 *Type 4 – vulnerability level 4.* The fourth group (n=17.69%) concerns household-representatives who claim to be aware of the precautions to take but do not know the civil protection guidelines. They have risk behaviour (wanting to return home during a flood) but they know about the causes of flooding. They think furthermore that the state is responsible for floods.

47 *Type 5 – vulnerability level 5.* The fifth group (12.72%) concerns households whose representatives are mainly illiterate, and have doubts about their knowledge (precaution, perception of the area, civil protection guidelines). They do not have risk

behaviour (going to see the flood) but do not think about clearing gutters to allow water to run off.

48 *Type 6 - vulnerability level 6.* The sixth group (6.27%) concerns poor households with household-representatives possessing a low level of education. They are aware of the precautions to take but not the civil protection instructions nor the cause of floods. They do not have risk behaviour.

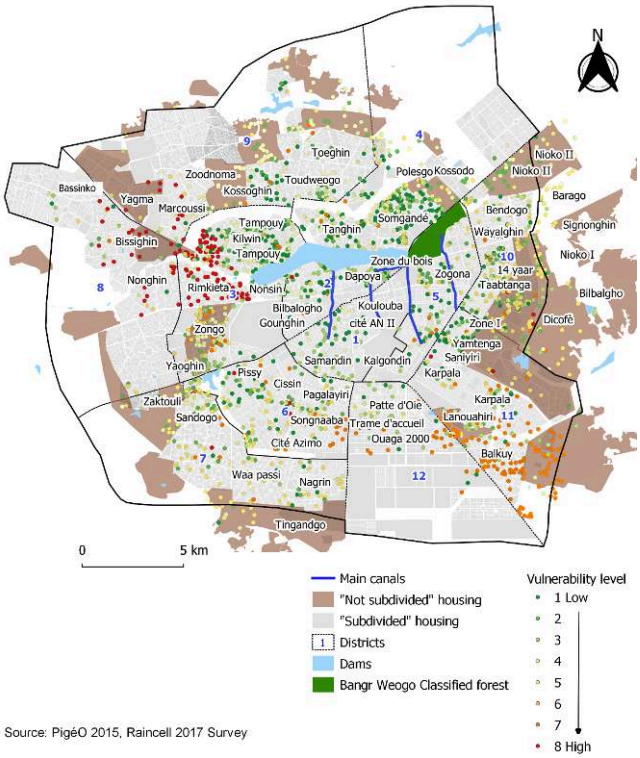
49 *Type 7 - vulnerability level 7.* The seventh group (10.81%) concerns the household-representatives with a low level of education who do not know the civil protection guidelines nor the precautions to take and have risk behaviour. They do not want to be warned in the event of a flood.

50 *Type 8 - vulnerability level 8.* The eighth group (17.74%) concerns household-representatives with a low level of education, who have several risk behaviours (going to see the flood, not staying where the flood took them by surprise) despite some knowledge of the causes of flooding. They have no knowledge, moreover, of the civil protection guidelines.

Spatial distribution of vulnerability profiles

51 Figure 7 shows the spatial location of respondents according to their vulnerability profile. This enables identification of settlements of the less vulnerable populations in the central zone of Ouagadougou, in particular the neighbourhoods of Koulouba, Larlé, Ouidi, Gounghin, Zogona-Wemtenga and Dassasgho. A wealth index and a high level of education as well as knowledge of the precautions to take contribute to a low vulnerability in this part of the city (Appendix D).

Figure 7: Vulnerability profile of Ouagadougou populations



Source: PigéO 2015, Raincell 2017 Survey

52 The sectors near the intra-urban dams (Dapoya, Tanghin, Somgandé) have themselves a low socio-spatial vulnerability index. This can be explained by the victim relocation measures that were undertaken by the municipality (Hangnon et al. 2018). As well, the effectiveness of the awareness campaign undertaken by the civil protection services in these neighbourhoods, and the acquisition of a certain risk culture, could also have contributed to improving the profile of the populations in this zone.

53 However, the most vulnerable zone is located in the outskirts of Ouagadougou, principally in the western zone in the neighbourhoods of Rimkieta, Bassinko, Marcoussi, Nonghin and Bissighin. A low level of education, risk behaviour as well as a lack of knowledge of the safety guidelines characterize the individuals in this group (Appendix C). Furthermore, the zones of Rimkieta-west and Balkuy are zones where no flood-linked regulations are applied, despite strong social vulnerability. These sectors, in fact, have been seriously affected by flooding in the last 20 years (Arcens Somé, 2012). These are zones situated near the shallows with a great biophysical vulnerability. A certain discrepancy exists, therefore, between the effective vulnerability and the flood regulations in these zones because the topography and social aspects are not criteria which are taken into account when delineating the zones at risk.

54 Vulnerability of the populations in the Rimkieta zone is all the greater as it constitutes, together with the neighbourhoods of Marcoussi and Zongo, places with the lowest wealth index (see Figure 3). Their inhabitants will consequently find it much harder to recover from the impact of a flood since the means at their disposal are not substantial enough.

55 What is more, Bassenko and Yagma constitute a new subdivided zone dating from the 2000s (Boyer, Delaunay, 2009) and displaced person sites from the 2009 flood (Essone Nkoghe, 2012). These displaced persons were not necessarily made aware of the precautions and behaviour to adopt, hence their great vulnerability.

Discussion

Natural flood-linked risks: the benefits of creating socio-spatial vulnerability profiles based on survey data

56 Social vulnerability is a complex, dynamic process which varies in time and space. Vulnerability indexes are a means with which to describe this complex reality simply and to enable inter-locality and intra-locality comparisons. For about twenty years, the emergence of the use of composite indicators has been observed in risk management, which denotes the desire of stakeholders and decision-makers to have an objective basis from which to direct their actions. Therefore, several stakeholders have worked to set up indexes to quantify the probability that a society will be adversely affected by a hazard (Fekete, 2009; Flanagan et al., 2011; Flanagan, Hallisey, Adams, Lavery, 2018; Rygel, O'sullivan, Yarnal, 2006). These different indexes make it possible, inter alia, to understand the vulnerability of diverse localities in the same country or continent and to establish comparisons (SoVI[12], World Risk Index, Floods vulnerability index etc.) or predict the resilience of societies (BRIC[13]...) (Cutter et al., 2003; Cutter, Burton, Emrich, 2010; Hugon, 2017; Karambiri et al., 2015). There are, moreover, a certain number of indexes (like the human development index, the economic vulnerability index, the physical vulnerability to climate change index, the living planet index, the city

development index, the ecological footprint, etc.) implemented in related disciplines in order to have a better understanding of societies (Böhringer, Jochem, 2007; Cutter et al., 2010).

57 However, all of these indexes cannot properly assess vulnerability because information is lost when attempting to synthesize it, despite its multidimensional nature, into a single index. Thus, they have been highly criticized in the scientific literature (Rakotoarisoa et al., 2018). Our typology approach, inspired by the work of Rufat (2013; 2019), which groups the population into several levels of vulnerability based on several specific factors, is therefore very appropriate.

58 Many of the aforementioned works on vulnerability assessment using indexes actually focus on the exposure of a population, an asset or a locality to risk. They therefore focus on the quantifiable characteristics of societies in order to analyse the potential of damage. However, social representations are essential aspects to take into consideration in order to understand how a risk is likely to have impacts on the territory (D'Ercole, Metzger, 2009). Indeed, the extent of losses, although linked to quantifiable socio-economic characteristics, will not be the same depending on the attitude of the populations affected by a risk. Indeed, social vulnerability cannot be reduced to a simple analysis of exposure to risk.

59 Vulnerability assessment therefore goes beyond exposure issues by analysing the occupancy of unsuitable buildings (Jonkman, Kelman, 2005; Vinet et al., 2011) and more generally land use, population behaviour before, during and after a flood (Ruin, 2007; Wilson, 2006), socio-economic conditions (financial and psychological capacities) as well as non-compliance with safety instructions. It is therefore necessary to determine different profiles that take into consideration the specificities of each area, taking into account both quantifiable socio-economic characteristics and psychosocial aspects, which incidentally remain undetectable by census data.

60 These census data are often either outdated or at scales that do not allow for local vulnerability analysis. For instance, in the case of Burkina Faso, the reports presenting the results of the 2020 general population census only presented data at a scale greater than or equal to the municipality. Analysing vulnerability at lower levels (e.g. by neighbourhood) is almost impossible with this type of data. Moreover, they tend to ignore the particularities and heterogeneity in each municipality. Our approach based on survey data is therefore more interesting.

61 Although there are limits to the profiles that we are putting in place, in particular in terms of replicability because of the costs of the surveys, it nevertheless makes it possible to mitigate certain deficiencies of indicators based only on quantifiable aspects of census data (Böhringer, Jochem, 2007; Jones, Andrey, 2007; Tate, 2012). For example, the selection of variables is not limited to available census data, but was thought out prior to the survey to take into account the holistic nature of vulnerability.

An original approach to determine vulnerability profiles and their underlying drivers

62 Our study on vulnerability profiles in Ouagadougou is essentially based on a sociological approach. The study of social vulnerability profiles is an alternative approach to indices that quantifies the vulnerability of a territory by aggregating

several variables into a single synthetic index. This method combines factor analysis and classification to determine spatially coherent vulnerability profiles. In our study, we opted for an hierarchical agglomerative clustering, which remains one of the most widely used methods in the literature. This clustering approach has been used to highlight population typologies in several studies with or without factor analysis as an input (Chang, Yip, Conger, Oulahen, Marteleira, 2018; Fischer, Chhatre, 2016; Rufat, 2013; Shukla, Agarwal, Gornott, Sachdeva, Joshi, 2019; Wood, Jones, Spielman, Schmidtlein, 2015).

63 The value of this approach is that it indicates the level of vulnerability of each profile but also explains the reasons for that vulnerability. At a spatial scale, the method is an opportunity to explain why some local areas are more vulnerable than others and thus to adopt targeted measures to improve the situation. Spatially representing vulnerability profiles therefore has policy implications by highlighting priority areas for assistance and coping capacity. As our results show, many variables are likely to have an impact on social vulnerability. The MCA carried out before the clustering is a good way to make a sparing selection of these variables. Combined with classification methods, it also offers the advantage of determining profiles on the basis of qualitative data.

64 However, some simplifications may threaten the validity of the method. The analysis, for example, is based on the relatively subjective choice of the number of dimensions to be retained in the MCA, which can have a significant effect on the final result. This subjectivity is linked to the existence of various criteria (elbow rule, Kaizer criterion, analysis of variance, etc.) for the choice of dimensions.

65 Although the employee classification method provides interesting results, it seems appropriate to consider a consolidation of the typology highlighted by the HAC. Indeed, many clustering methods have emerged for several years now (dynamic clouds method, fuzzy method, self-organizing map...). Some of them, such as the K-means method, have already been used in studies successfully and could be considered in our case to reinforce the coherence of clusters.

Urban policies, risk behaviours and social status: three key factors of social-spatial vulnerability

66 Individuals showing a high level of social vulnerability can be found in particular on the urban fringes on the outskirts, essentially in non-subdivided housing areas.

67 The most vulnerable populations, therefore, shown by our analysis, are the populations which have a tendency to adopt risk behaviours in going to see the flood or in not staying where they are when a flood occurs. Observable risk-taking behaviour could be justified by minimizing the impacts of the disaster and the belief in the effectiveness of coping strategies. These behaviours can largely be understood as *"the thrill of the sight of a flood"* (Wilson, 2006, p. 59), the desire to offer assistance in the event of people in difficulty or of not wanting to leave their goods unattended. Wilson (2006) talks of a "*normality bias*" for the loss of goods is often interpreted by the victims in terms of known consequences whereas the risk of death from a flood is unknown, difficult to predict and often minimized. Risk behaviour is seen in the same vein, therefore, as strategies implemented by populations to "cope" with risks. Colbeau (2002) shows that these strategies take account of cognitive and social aspects in conjunction with the

perception of risk, of relativizing the situation, the desire to regain a certain control and the level of stress induced by danger.

68 Beyond these cognitive aspects highlighted by our study, some studies on West African towns have already confirmed the heightened vulnerability to floods of populations living in the outskirts (Diongue, 2014; Ould Sidi Cheikh, Ozer, Ozer, 2007). These spaces in Ouagadougou, built using precarious materials and not complying with any planning laws, testify to the difficulties that the public authorities have in implementing planning schedules capable of anticipating urban growth. Despite a voluntary urban policy under the revolutionary regime, determined to curb definitively these housing pockets of often precarious populations (Fournet, Meunier-Nikiema, Salem, 2008), these forms of space occupancy have remained. Indeed, urban spatial extension has contributed progressively to the absorption of rural territories, encroached on by the city, with no urban planning document defining the places and spaces of installation of rainwater collection systems to counter the effects of runoff[14].

69 To reduce social vulnerability in Ouagadougou, policies to fight against poverty and flooding should be implemented as well as awareness systems which can be effectively disseminated to populations. Awareness has already been initiated by the state using the print media to disseminate the proper conduct to have in the event of flooding, but the question arises as to the effectiveness and adequacy of this written mode of raising awareness in a country where the rate of illiteracy is close to 75% (INSD, 2015).

Conclusion

70 Preparing for, coping with, protecting against, and recovering from floods depends as much on an individual's intrinsic characteristics (socio-demographics, income, knowledge etc.) as their ability to correctly assess hazards, adopt appropriate behaviour, and cope with risk. In our study, the large amounts of data collected and the statistical techniques used allowed for a comprehensive analysis without preconceived ideas about the knowledge and spatial distribution of social vulnerability levels in Ouagadougou.

71 Our study provides managers with a framework for understanding and assessing social vulnerability. However, although the implemented classification method is highly interesting, it can be improved, mainly through consolidation techniques for identified clusters.

72 In view of the results obtained, it appears that for a more effective management of flood risks, the city of Ouagadougou should focus on certain measures. These include improving the living conditions of the population (fighting poverty and illiteracy) and raising their awareness to promote appropriate behaviour. Furthermore, improvement in housing conditions by means of better spatial organization of dwellings is an important line to define in urban planning documentation. Developing social housing in the city might reduce the pressure on informal settlements and limit land-use speculation.

73 In our study, we have discussed the constraints of using census data for classification. However, the costs of implementing the urban survey we used (about 10 000 euros just for the survey) can be a significant barrier to identifying and characterizing

vulnerability profiles. Reflection is therefore necessary to facilitate this type of evaluation on a regular basis and in several localities.

74 If alternatives are developed to facilitate access to data, particularly qualitative data, the social vulnerability profiles method could be considered as a multi-scale technique for assessing and understanding vulnerability at both local and sub-regional levels.

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APPENDIXES

Appendix A: Chi-square test on variables

	p.value	df
Wealth_index	0	28
warning	0	14
see_out	0	7
percep_zone	4.93E-272	14
education	2.60E-217	28
cp_instruc	1.27E-177	14
c_floodplain_urb	8.01E-74	7
flood_time	2.65E-64	14
home_digging	5.07E-61	7
stay_out	1.09E-53	7
resp_state	1.11E-50	7
home_clean	2.06E-17	7
norm_flood	2.69E-06	7

Appendix B: Eigenvalues and percentage variance explained by 10 dimensions using MCA output

	eigenvalue	Variance explained (%)	Cumulative variance (%)
dim 1	0.149	8.41	8.41
dim 2	0.120	6.77	15.18
dim 3	0.106	5.99	21.18
dim 4	0.101	5.71	26.89
dim 5	0.089	5.04	31.93
dim 6	0.087	4.92	36.84
dim 7	0.083	4.68	41.52
dim 8	0.082	4.64	46.16
dim 9	0.079	4.48	50.63
dim 10	0.076	4.30	54.93

Appendix C: Variable loadings of different variables and categories on the resultant 10 factors

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8	Dim.9	Dim.10
Wealth_index	0.480	0.109	0.053	0.037	0.131	0.247	0.148	0.210	0.531	0.280
education	0.420	0.060	0.111	0.108	0.216	0.124	0.171	0.237	0.069	0.290
flood_time	0.136	0.272	0.221	0.009	0.037	0.019	0.030	0.065	0.112	0.082
norm_flood	0.026	0.000	0.001	0.003	0.329	0.013	0.019	0.207	0.000	0.037
resp_state	0.153	0.001	0.044	0.012	0.107	0.034	0.013	0.015	0.020	0.089
c_floodplain_urb	0.196	0.001	0.018	0.207	0.001	0.003	0.030	0.000	0.073	0.005
percep_zone	0.193	0.185	0.035	0.050	0.140	0.100	0.261	0.112	0.052	0.007
warning	0.099	0.335	0.190	0.227	0.045	0.071	0.165	0.034	0.014	0.002
cp_instruc	0.152	0.313	0.044	0.074	0.111	0.160	0.048	0.101	0.028	0.086
home_digging	0.014	0.210	0.017	0.003	0.008	0.132	0.099	0.015	0.071	0.084

home_clean	0.048	0.002	0.215	0.091	0.002	0.104	0.069	0.014	0.010	0.007
stay_out	0.017	0.027	0.001	0.406	0.005	0.120	0.023	0.001	0.043	0.013
see_out	0.001	0.042	0.427	0.087	0.026	0.003	0.001	0.054	0.005	0.006

Appendix D: Main categories correlated to each cluster

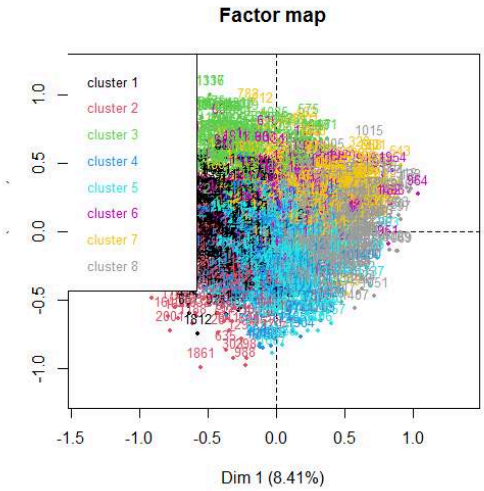
Vulnerability level	Variables	Cla.Mod	Mod.Cla	Global	p.value	v.test
1	see_out=see_out_No	19.0	100.0	93.4	0.0	7.3
	warning=warning_Yes	20.7	95.0	81.3	0.0	8.4
	percep_zone=percep_zone_none	22.7	93.1	72.7	0.0	10.9
	resp_state=resp_state_Yes	21.4	91.6	75.9	0.0	8.5
	norm_flood=abnormal	16.5	82.8	89.0	0.0	-4.0
	c_floodplain_urb=c_floodplain_urb_Yes	24.0	82.1	60.6	0.0	9.9
	Wealth_index=5	62.9	70.7	19.9	0.0	24.7
	home_digging=home_digging_No	24.0	55.9	41.4	0.0	6.3
	education=university	72.9	52.5	12.8	0.0	22.2
2	see_out=see_out_No	13.6	99.6	93.4	0.0	5.5
	warning=warning_Yes	15.4	98.2	81.3	0.0	9.1
	Wealth_index=3	60.0	94.1	20.0	0.0	29.5
	home_digging=home_digging_Yes	14.3	65.8	58.6	0.0	2.6
	c_floodplain_urb=c_floodplain_urb_No	18.4	57.0	39.4	0.0	6.2
3	see_out=see_out_No	11.4	98.3	93.4	0.0	3.6
	warning=warning_Yes	12.8	96.1	81.3	0.0	7.0
	resp_state=resp_state_Yes	12.6	88.7	75.9	0.0	5.1
	c_floodplain_urb=c_floodplain_urb_Yes	12.8	71.9	60.6	0.0	3.8
	flood_time=2h	15.2	68.4	48.6	0.0	6.4
	cp_instruc=cp_instruc_Yes	48.0	66.2	14.9	0.0	19.4

	percep_zone=percep_zone_floodable/ forbidden	79.5	57.1	7.8	0.0	22.5
	home_digging=home_digging_No	14.7	56.3	41.4	0.0	4.8
4	see_out=see_out_No	18.9	99.7	93.4	0.0	6.8
	warning=warning_Yes	21.3	97.9	81.3	0.0	10.7
	percep_zone=percep_zone_none	22.1	90.7	72.7	0.0	9.4
	resp_state=resp_state_Yes	20.1	86.5	75.9	0.0	5.5
	stay_out=stay_out_No	21.5	84.9	69.8	0.0	7.4
	home_digging=home_digging_Yes	24.6	81.5	58.6	0.0	10.3
	c_floodplain_urb=c_floodplain_urb_Yes	20.2	69.3	60.6	0.0	3.9
	cp_instruc=cp_instruc_No	15.4	56.3	64.8	0.0	-3.7
	flood_time=1/2d	24.8	48.1	34.4	0.0	6.1
	Wealth_index=2	40.9	46.3	20.0	0.0	13.0
5	see_out=see_out_No	6.8	98.6	93.4	0.0	2.9
	home_clean=home_clean_No	7.3	95.7	84.7	0.0	4.1
	warning=warning_Idk	74.4	84.1	7.3	0.0	24.5
	resp_state=resp_state_Yes	5.7	67.4	75.9	0.0	-2.4
	percep_zone=percep_zone_Idk	20.3	61.6	19.6	0.0	11.3
	education=never_school	9.6	61.6	41.3	0.0	4.9
	flood_time=2h	7.8	58.7	48.6	0.0	2.4
	cp_instruc=cp_instruc_Idk	18.4	58.0	20.3	0.0	10.1
	cp_instruc=cp_instruc_No	4.1	41.3	64.8	0.0	-5.8
6	see_out=see_out_No	19.4	99.7	93.4	0.0	6.9
	warning=warning_Yes	21.8	97.4	81.3	0.0	10.5
	norm_flood=abnormal	19.5	95.1	89.0	0.0	4.6
	cp_instruc=cp_instruc_No	24.1	85.9	64.8	0.0	10.2
	home_digging=home_digging_Yes	22.3	72.0	58.6	0.0	6.0
	c_floodplain_urb=c_floodplain_urb_No	33.1	71.7	39.4	0.0	14.3

	education=never_school	28.5	64.8	41.3	0.0	10.3
	stay_out=stay_out_Yes	36.8	61.2	30.2	0.0	14.1
	Wealth_index=1	51.8	56.8	20.0	0.0	18.4
	percep_zone=percep_zone_none	13.9	55.5	72.7	0.0	-8.1
	resp_state=resp_state_Yes	12.1	50.4	75.9	0.0	-12.3
	resp_state=resp_state_No	37.5	49.6	24.1	0.0	12.3
	percep_zone=percep_zone_Idk	40.2	43.2	19.6	0.0	12.1
7	see_out=see_out_No	10.6	98.1	93.4	0.0	3.3
	home_clean=home_clean_No	11.4	95.4	84.7	0.0	5.1
	cp_instruc=cp_instruc_No	14.5	93.1	64.8	0.0	10.2
	percep_zone=percep_zone_none	12.9	92.6	72.7	0.0	7.7
	warning=warning_No	81.5	91.7	11.4	0.0	31.0
	stay_out=stay_out_No	12.3	84.7	69.8	0.0	5.3
	norm_flood=abnormal	9.6	84.3	89.0	0.0	-2.2
	home_digging=home_digging_No	19.3	79.2	41.4	0.0	11.9
	flood_time=2h	16.3	78.2	48.6	0.0	9.4
	resp_state=resp_state_Yes	9.4	70.4	75.9	0.0	-2.0
	education=never_school	16.4	67.1	41.3	0.0	8.1
	c_floodplain_urb=c_floodplain_urb_Yes	9.0	53.7	60.6	0.0	-2.2
8	see_out=see_out_Yes	90.8	96.3	6.6	0.0	29.0
	c_floodplain_urb=c_floodplain_urb_Yes	9.4	91.0	60.6	0.0	8.1
	stay_out=stay_out_No	7.9	88.1	69.8	0.0	5.1
	cp_instruc=cp_instruc_No	7.8	80.6	64.8	0.0	4.1
	warning=warning_Yes	5.8	74.6	81.3	0.0	-2.0
	resp_state=resp_state_Yes	5.4	65.7	75.9	0.0	-2.8
	home_clean=home_clean_No	4.5	61.2	84.7	0.0	-6.9
	education=never_school	7.6	50.0	41.3	0.0	2.1

	flood_time=+1day	14.9	40.3	17.0	0.0	6.6
	home_clean=home_clean_Yes	15.9	38.8	15.3	0.0	6.9
	resp_state=resp_state_No	8.9	34.3	24.1	0.0	2.8
	Wealth_index=1	8.7	27.6	20.0	0.0	2.2

Appendix E: Factor map



Appendix F: Questionnaire

Introduction

Hello,

I'm part of a project aiming at understanding how flooding appears in Ouagadougou and its effects. Would you agree to participate in this survey? It takes 15 minutes and is anonymous.

a. Have you lived here for more than 2 years?

Yes

No → *go to the end*

b. As a resident, are you

Permanent

Temporary → *go to the end*

c. Are you the head of the household (or the wife/husband, child, cousin)?

Yes

No → *go to the end*

d. How old are you?

(*integer*)

Under 18 → *go to the end*

e. Explicit agreement to answer

Yes

No → *go to the end*

VOLUNTARY PARTICIPATION

Your household was chosen to be part of our one-off flood survey. The questionnaire is anonymous and we ensure the confidentiality of your participation in the study and the content of your answers.

When analysing the results, there will be no mention of your identity or any statement that may allow you to be recognized. The results of the study will provide the authorities with tools to improve the prevention of flood risk.

Your participation is up to you and voluntary. Failure to participate does not entail any sanction whatsoever.

CONTACT FOR MORE INFORMATION:

If you have any questions, please ask them now or later on. If you prefer to do it later, you can contact:

Emmanuel Bonnet, IRD, tel: 00 226 66 98 35 69

Aude Nikiema, INSS, tel: 00 226 70 22 16 30

Electronic signature

Yes

No → *go to the end*

Personal information

Sex

Male

Female

Marital status

Married

Cohabitation

Widowed

Single

Divorced

How many people regularly live there (more than 6 months and under the authority of the household's head)?

(*integer*)

What is your religion?

Animist

Christian

Muslim

Other

None

What is your main occupation?

Student

Farmer / vegetable producer

Fisherman / cattle breeder

Craftsman

Public employee

Private employee

Liberal Profession

Shopkeeper

Retired

Business Executive

Unemployed

What is your educational background?

Never went to go school

Literate

Koranic school

Primary school

Secondary school

Higher education / University

Ownership status of the household

The head of the household is the owner

The head of the household rents

The head of the household occupies the house for free

How long has your family lived in the area?

2 to 5 years

6 to 10 years

10 to 20 years

More than 29 years

Always

Now, we are going to talk about flooding in general, according to what you know.

Generally speaking, have you ever experienced a flood?

Yes

No

According to you, to consider there is a flood, the water should remain for at least

2 hours

Half a day

One day

Many days

According to you, to consider there is a flood, the water should reach at least

Up to the ankle

Up to the knee

Up to the waist

Up to the shoulder

According to you, during the rainy season, floods are

Normal

Not normal

Would you say that the effects of floods are a disaster

That cannot be prevented

That can partly be prevented

That can largely be prevented

That can totally be prevented

Would you say that the state authorities are responsible for floods?

Yes

No

Would you say that local communities are responsible for floods?

Yes

No

Would you say that some people are responsible for the floods?

Yes

No

Would you say it is God's will?

Yes

No

According to you, what causes floods?

Lack of dams

Construction in flood prone areas

Lack of gutters

Garbage in gutters

The climate change

Would you say that the place you're living is prone to floods?

Very slightly

Slightly

Strongly

Very strongly

Not at all

We are now talking about the way your plot is adapted to floods

Has this plot already been damaged by floods?

Yes

No → *go to Q31*

When was this?

(integer)

That year, what damage was caused among the following:

Wall partly fallen

Crack in the wall

Damaged roof

Damaged furniture and goods in the house

Loss of personal belongings

Loss of cattle or crops

No damage

How high was the water that time?

Up to the ankle

Up to the knee

Up to the waist

Up to the shoulder

After that, did you rebuild or buy again what was damaged/missing?

Yes

No → *go to Q31*

Did you rebuild fallen walls?

No

Partly

As before

Better than before

Did you rebuild the roof?

No

Partly

As before

Better than before

Did you get your goods back?

No

Partly

As before

Better than before

Did you get your cattle and crops back?

No

Partly

As before

Better than before

What did you rebuild your home with?

Mud (“banco”)

Enhanced mud (mud melted with cement)

Cement and other materials

Building bricks and cement

How did you rebuild your home?

Same level

Higher

With an extra floor

To evaluate the potential damage, we would like to know how many of these you have?

Car

Motorcycles

Bike

Fridge

TV

Radio

Mobile phone

Are you connected to the electricity service (Sonabel)?

Yes

No

Are you connected to the water supply (Onéa)?

Yes

No

Now, I'd like to talk about the regulations and laws

Have you ever heard of a law for floods?

Yes

No

Don't know

Indeed, there is a law with regard to floods. Do you think you live in an area

Where it is prohibited to build because of flooding

Prone to floods

Neither one nor the other

Don't know

Whatever area you live, do you think you should take precautions concerning floods?

Yes

No → *go to Q39*

Don't know → *go to Q39*

If yes, what would be the precautions concerning materials?

Build with enhanced mud (mud melted with cement)

Build with cement and other materials

Build with bricks and cement

If yes, what would be the precautions with the house?

Higher foundations

Build with an extra floor

Do not rebuild there

Have you ever heard of precautionary instructions concerning floods disseminated by the civil defense?

Yes

No

Before we finish, let's speak about the warning system

Nowadays it is possible to announce heavy rains many hours before it falls. If possible, would you like to receive that information?

Yes

No → *go to Q42*

How would you prefer to be informed?

Town crier

Announcements on all radio stations

Phone text

Announcements on all TV channels

App on a smartphone

Alert announced by siren?

Others: _ _ _

When at home, what do you do if you're informed of such heavy rain?

I dig so that the water can flow

I clean gutters

I block doors and windows

I raise furniture up

I do nothing

When out, what should you do if you're informed of such heavy rain?

Stay where you are and wait for the rain to stop

Go back home

Move to another area

Go and see the flood

The survey is now over; would you agree to be contacted to test a flood alarm system?

Yes

No → *go to Q 46*

If Yes, phone number

(phone number)

Observations (interviewer only)

Main material of construction

Mud (“banco”)

Enhanced mud (mud melted with cement)

Cement and other materials

Building bricks and cement

Foundations

No foundations

Foundations with mud (“banco”)

Foundations with enhanced mud (mud melted with cement)

Foundations with cement and other materials

Foundations with building bricks and cement

Hidden

Household type

Simple house

Executive house

Collective housing for singles (“celibatorium”)

Residential building

Family court

Other:

Shop in the plot

Yes

No

Gutters in front of the house

Yes

No

Asphalted road

Yes

No

Spatial sample

Zone 1

Zone 2

Zone 3

Zone 4

GPS coordinates

Date

Interviewer's name

Id survey

Comments

NOTES

1. This method is based on a two-step approach: determining vulnerability profiles through a factor analysis and a clustering method, and using GIS to analyse the spatial distribution of vulnerability profiles.

2. This questionnaire, written in French and Moré, was implemented on a smartphone using the kobotoolbox application to ensure that all the questions were answered and to allow for the geolocation of respondents.

3. The size of the sample is calculated by means of the formula of Réa et al. (1997) cited by par Gabert (Gabert, 2018):

$$n = \frac{t_p^2 * P(1-P) * N}{t_p^2 * P(1-P) + (N-1) * y^2}$$ n: size of the sample

N: estimated size of the target population

P = 0.5

tp = 2.69 for a confidence interval of 99%.

y = 3% margin of error of the sampling

After calculation, the sample size was determined to be at least 2000 people at the 99% confidence level.

4. Zone 1: zone of application of the law on flooding: building is prohibited or subject to specific construction rules. The settlement of populations in these zones, particularly to the south of the dams, notably in the districts of Dapoya, Ouidi and Larlé, part of which is in a flood zone, dates back to pre-colonial times. These were traditional villages located near the palace of the Mogho-naba, the traditional chief of Ouagadougou (Tiendrebeogo, 1963), but also near the marshes. With the various subdivisions of the city, particularly during the years 1983-1987, these villages evolved into the current neighbourhoods. Also, the large *marigots* have gradually been transformed into urban dams (Fournet et al., 2008).

Zone 2: zone where no regulations apply despite numerous floods since 2009 according to the written press

Zone 3: zone where no flood regulations apply and where floods remain very rare even in the press

Zone 4: zone with "slums", despite the law on no construction, outside zone 1 and 2

5. After the floods of 01/09/2009, decree N°2009-793/PRES/PM/MHU/MATD/MEF/MID/MAHRH/MECV (Président du Faso, 2009) relating to the delineation of Ouagadougou's flood-prone zones was adopted. It stipulates that the non-constructible flood-prone zones comprise easement areas of 100 metres on both sides of the boundaries of primary runoff canals, and the areas below the shores of the dams' lakes and natural ponds corresponding to the ten-year flood.

6. Formal zones are legally urbanized areas listed in urban planning documents while informal areas are the result of anachronistic and unplanned occupation

7. correlation tests are presented in Appendix A

8. Eviction: is a term used in Ouagadougou and refers to the expropriation and relocation of populations by the local authorities for the application of urban policies or for the requirements of management (protection of populations in the face of risks, etc.)

9. Figure 6 is inspired by the results of the factor map presented in appendix E and obtained by hierarchical agglomerative clustering

10. The civil protection guidelines: concern the advice disseminated by the civil protection services on what to do in the event of flood risk. Certain populations received the leaflet following the 1st September 2009 floods, which furthermore were published in the print media (Lefaso.net, 2011).

11. The precautions to take: concern the behaviour and actions to adopt to protect oneself from floods. This refers to personal and/or collective knowledge which can include the civil protection instructions or not. For example, clearing gutters is a precaution to take which is not mentioned in the guidelines disseminated by the civil protection.

12. SoVI: Social Vulnerability index. Implemented by Cutter, makes it possible to compare the vulnerability of several localities based on the data from the population census.

13. Baseline Resilience Index for Community. This index, implemented in the United States of America by Cutter, makes it possible to determine and compare the resilience of communities of several zones based on social, economic, institutional, community factors and infrastructures.

14. In addition to deficiencies in terms of rainwater collection facilities, the question of maintaining them arises in order to prepare for flood risks. Deficiencies have been observed despite an almost annual flushing of the few gutters that are there. There is a tendency of part of the population to use the collection tanks to dispose of refuse during the rainy season. This situation is made worse by widespread fly-tipping done by the populations themselves using the official sites to dump the waste (Sory, Tallet, 2012).

ABSTRACTS

The inhabitants of the city of Ouagadougou, the capital of Burkina Faso, suffer significant damage every year due to floods, which constitute a major risk for the country. To mitigate the impact of these phenomena, a good understanding of the criteria involved in the vulnerability of populations is necessary.

This article sets out to analyse the populations of Ouagadougou's vulnerability to floods, with the objective of drawing up and spatially representing the social vulnerability profile of populations. It is part of phase 2 of the Raincell Africa project, which aims to understand the social vulnerability of Sahelian populations to the risks of urban flooding.

The study is based on a quantitative approach developed by means of a socio-demographic survey of 2137 households in the city of Ouagadougou.

Statistical processing of the survey data using factor analysis and Hierarchical Agglomerative Clustering revealed eight vulnerability profiles in the city. The spatial distribution of these profiles indicates greater vulnerability in the margins of the city, characterized by unplanned settlements. This high exposure of informal settlements to flooding is linked to socio-demographic characteristics such as the level of education, risky behaviours in terms of urbanization and the populations' false perception of danger. These elements must necessarily be taken into account for better flood management.

Les habitants de la ville de Ouagadougou, capitale du Burkina Faso, subissent chaque année d'importants dégâts à cause des inondations, qui constituent d'ailleurs un risque majeur pour le pays. Pour atténuer l'impact de ces phénomènes, une bonne compréhension des critères

impliqués dans la vulnérabilité des populations est nécessaire. Cet article se propose d'analyser la vulnérabilité des Ouagalais face aux inondations, avec pour objectif de dresser et de représenter spatialement le profil de vulnérabilité sociale des populations. Il s'inscrit dans le cadre de la phase 2 du projet Raincell Africa, qui vise à comprendre la vulnérabilité sociale des populations sahéliennes face aux risques d'inondations urbaines. L'étude repose sur une approche quantitative développée à travers une enquête sociodémographique auprès de 2137 ménages de la ville de Ouagadougou. Le traitement statistique des données d'enquête par analyse factorielle et classification ascendante hiérarchique a permis de mettre en lumière huit profils de vulnérabilité dans la ville. La répartition spatiale de ces profils indique une plus grande vulnérabilité dans les marges de la ville, caractérisées par un habitat spontané informel. Cette forte exposition des populations des quartiers informels aux inondations est liée aux caractéristiques sociodémographiques telles que le niveau d'étude, les comportements à risque en termes d'urbanisation et une perception erronée du danger par les populations. Ces éléments doivent nécessairement être pris en compte pour une meilleure gestion des crues.

Los habitantes de la ciudad de Uagadugú, capital de Burkina Faso, cada año experimentan considerables daños a causa de las inundaciones, las cuales constituyen un elevado riesgo para el país. Para mitigar el impacto de tal fenómeno, resulta necesario un acabado conocimiento de los elementos que intervienen en la vulnerabilidad de la población.
Este artículo propone analizar la vulnerabilidad de los habitantes de Ouagadougou frente a las inundaciones, con el objetivo de elaborar y representar espacialmente el perfil de vulnerabilidad social de tal población. El trabajo se enmarca en la segunda fase del proyecto Raincell África, que tiene como objetivo comprender la vulnerabilidad social de las poblaciones del Sahel frente a los riesgos de inundaciones urbanas.
El estudio se sostiene en un enfoque cuantitativo desarrollado por medio de una encuesta sociodemográfica a 2137 hogares en la ciudad de Uagadugú, a la cual se le aplica un análisis factorial y clasificación ascendente jerárquica, dando como resultado ocho perfiles de vulnerabilidad en la ciudad. La distribución espacial de estos perfiles indica una mayor vulnerabilidad y alta exposición en los márgenes de la ciudad, caracterizados por asentamientos humanos que no han sido sujetos a planificación y los cuales se asocian a características sociodemográficas como el nivel de educación, comportamientos de riesgo en cuanto a la urbanización y la falsa percepción de peligro de la población. Tales aspectos deben ser considerados para propiciar una mejor gestión de las inundaciones.

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Keywords: urban vulnerability, flood, individual and collective human behaviour, risk perception, survey
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