Technical Report No. V

BUILD RELATIONSHIP BETWEEN FLOOD DEPTH AND LIKELY DAMAGE (DEPTH-DAMAGE CURVES)

Start date of project: 01 June 2015
Duration: 48 months

Lead partner for the report: **2iE**

Authors: H. KARAMBIRI, FOWE TAZEN, M. BOLOGO/TRAORE, L. A. MOUNIROU G. COULIBALY, K. TRAORE

AMMA-2050 is funded under the Future Climate for Africa Programme which is supported by funding from the NERC and DFID

The AMMA-2050 project started 01/06/2015 and will continue for 4 years.

Title:	Future Pilot Floods
Authors:	H. KARAMBIRI, FOWE TAZEN, M. BOLOGO/TRAORE, L. A. MOUNIROU, G. COULIBALY, K. TRAORE
Organisations:	2iE
Submission date:	September 2018
Function:	This report is an output from Work Package 6; task 6.3.3
Available from	<insert web link>

'The research leading to these results has received (partial) funding from the NERC/DFID Future Climate For Africa programme under the AMMA-2050 project, grant number NEC05274.

Publishable Summary

Floods regularly cause considerable and sometimes catastrophic damage on environments, human activities and economies. Their management is now based on a good knowledge of the phenomenon and in a preventive approach of sustainable development. Because of the significant cost of protective developments, decision-makers need an estimate of potential damage in order to assess the relevance of these investments. For this study, flood-damage curves are adopted as a tool for estimating potential damage. A survey of two hundred and forty-three (243) households in flood zones in the "Grand Ouaga" area of Burkina Faso has allowed the construction of empirical laws of damage depending on submersion. Thus, three functional relationships are established depending on the nature of the housing construction material. The results indicate that the cost of potential damage to the structure for floodplain dwellings on the edge of the city's dams is estimated at three hundred and twenty-nine million one hundred and sixty one thousand five hundred and thirty-seven CFA francs (329 161,537 FCFA) for an average water depth of 0.6 m observed from the 2009 floods (1st September) considered as the higher extreme event in Burkina in general and in the city of Ouagadougou in particular.

The functions developed for the floodplain dwellings of the "Grand Ouaga" area are considered in the appropriate set and can constitute a starting point for the development of this particularly useful tool, which is the submergence-damage curve.

Key words: flooding, damage curves, flood zone housing, "Grand Ouaga" area, Burkina Faso

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Flood is among the most damaging natural disasters in the world (Blin, 2001). Although they do not have the scale of certain catastrophes such as volcanoes or tropical hurricanes, they constitute the best distributed risk on the planet (CatNat, 2010). These flood events are becoming increasingly worrying and difficult to manage because of their recurrence in some parts of the world, their dependence on climate change, and the high population pressure especially in urban areas. After the droughts of the 1970s and 1980s, the countries of West Africa and the Sahel are experiencing a resurgence of heavy rainfall and floods, the consequences of which are deplorable (AGRHYMET Regional Center, 2010).

In Burkina Faso, between 1991 and 2009 eleven (11) major floods were counted (EM-DAT base, FEWS-NET, 2014). And the most destructive is that of 2009 where there were recorded at the level of the city of Ouagadougou and its surrounding 150 000 victims, more than 24 000 homes destroyed and at least 9 dead (SP / CONASUR, 2009).

In the context of global reflections on climate change, the level of resilience of African cities to extreme events is an important issue. Indeed, a more intense flood than that of 2009 could represent a major shock and an unprecedented challenge for public policies. In this context, the assessment of potential ex-ante damage is a powerful indicator of vulnerability, which could enable decision-makers to judge the relevance of flood management projects (Eleutério, Rozan and Payraudeau, 2009, Eleutério, Mosé and Rozan., 2012).

Flood damage depends on the characteristics of the flood, including the area covered, the depth and duration of floods, the speed of runoff, the frequency of precipitation, the sediment content of the water and the level of flooding (Soetanto and Proverbs, 2004). This damage can be tangible and intangible. Tangible damages can be subdivided into direct and indirect damages. Direct damage results from direct contact of flood water with damaging property and the extent of damage is assumed to be the cost of restoring this property to its pre-flood state or current market value if the restoration is impracticable. Indirect damages are losses caused by the disruption of physical and economic links, including loss of production, loss of revenue, loss of business and delays in the transportation of goods. Intangible damage includes fear, anxiety, annoyance, health, and loss of life (Laurent, 2005).

In this study we are interested in direct damage and more particularly damage to housing in the "Grand Ouaga" area in Burkina Faso. This estimate assesses, in monetary terms, the impacts generated by the floods on the housing structure on the basis of information obtained through the surveys of inhabitants of the flood zones of the "Grand Ouaga" area.

1. MATERIAL AND METHODS

1.1 Presentation of the study area

Located in the heart of Burkina Faso, the "Grand Ouaga" space comes from the master plan for the expansion of the city of Ouagadougou by 2025 and lies between the parallels 12 ° and 13 ° north latitude and between the meridians 1 ° and 2 ° west longitude. It is the territory covering the urban commune of Ouagadougou (capital of Burkina Faso) and the seven (07) surrounding rural communes that are: Koubri, Komsilga, Komki-Ipala, Saaba, Pabre, Tanghin-Dassouri and Loumbila (Figure 1) .

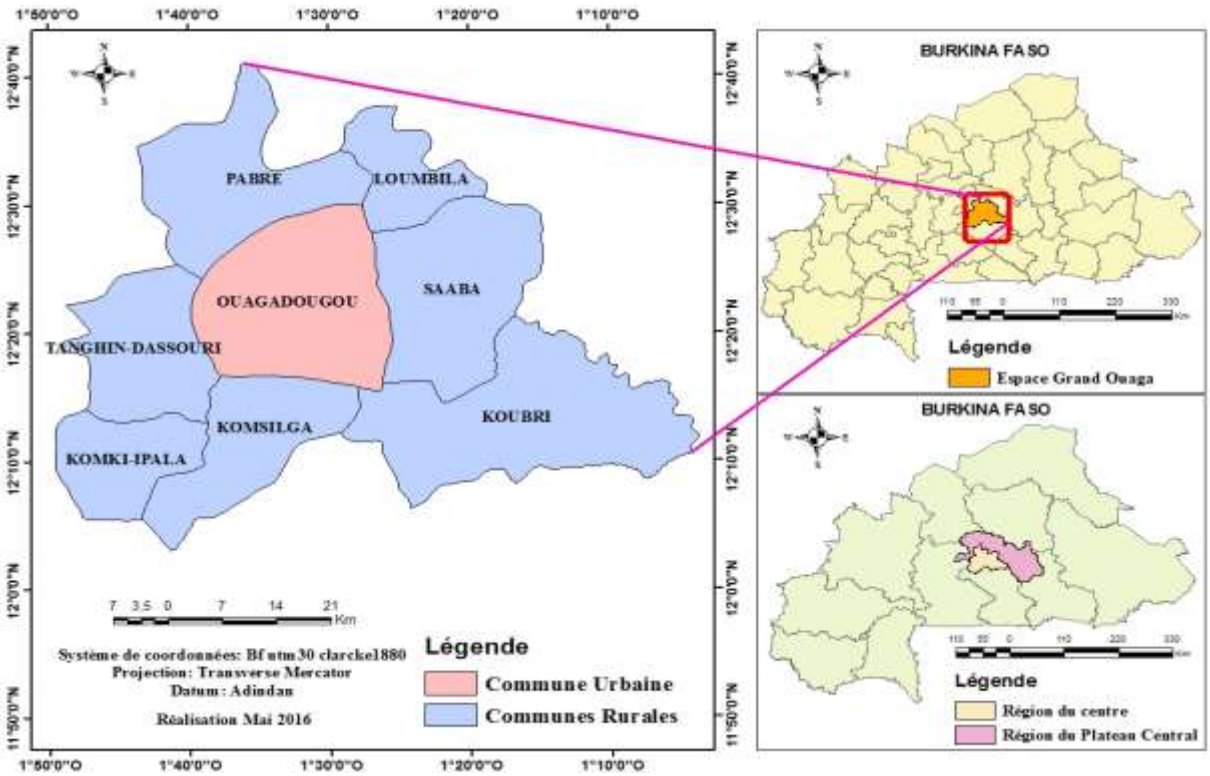

Figure 1: Administrative map of the "Grand Ouaga" area

The Grand Ouaga as a whole has a flat profile with relatively low slopes (less than 2%). The soil of the "Grand Ouaga" is predominantly dominated by hydromorphic soils covering watercourses, poorly evolved soils, and impregnated soils, particularly in the city of Ouagadougou.

Located between the 700 and 1000 mm isohyets, the "Grand Ouaga" area belongs to the Sudano-Sahelian climate zone of Burkina Faso, characterized by the alternation of two seasons:

- A dry season of seven (07) months (from November to May) marked by the harmattan;

- A rainy season of five (05) months (from June to October) announced by the monsoon (with an abundance of rains in August).

Grand Ouaga has an area of approximately 3,304 km^2. According to the projections of the National Institute of Statistics and Demography (INSD) the population of Grand Ouaga is estimated at 2,601,525 inhabitants in 2018. In general, it is an area whose population grows a lot with a rate of annual growth of 4.78% (INSD, 2006), but it also attracts new populations from rural areas. Between 1985 and 2006, the population density increased by 40%. In 2025, horizon of the scheme, the population of Grand Ouaga will be about 4,713,077 inhabitants.

1.2 Construction of the damage function

Potential damage due to flooding is usually translated through damage curves. A damage curve is a damage function that combines damage costs established for a type of stake based on the physical parameters of the hazards. These parameters can be: water depth, submersion time, current speed, water rise rate and sediment load (Ledoux and Hubert, 1999).

Damage estimation methods mainly concern direct damage. Other types of damage are difficult, and for some, impossible to evaluate economically. This study focuses on direct damage to housing structure. The damage function can then be as follows:

$$\boldsymbol{D} = \boldsymbol{f}(\boldsymbol{K}, \boldsymbol{Y}) \qquad [\mathbf{1}]$$

Where K is a vector describing an individual building or the whole physical capital and Y is a vector characterizing the hazard.

The water depth is the physical parameter that is retained in this study because it is quantitative in nature and easier to obtain. It is a variable that explains much of the damage caused by floods to buildings (Genovese, 2006).

The function which links the rate of damage to the submersion depth is generally monotonous, continuous and positive definite between 0 and 1, increasing and having an "S" shape (Danzig, 1956). Several types of curves (linear, exponential, polynomial, and logarithmic) are commonly used to perform regressions. However, Gompertz's law is more in keeping with the characteristics described by Danzig (1956) concerning damage functions..

$$Txe = ae^{-b.e^{-k.H}} \qquad [2]$$

Where Txe is the damage rate and H the submersion depth in meters .a, b and k are the parameters to be determined.

These parameters were estimated from the Statistical Analysis System (SAS) Version 9.2 environment.

The coefficient of determination R^2 made it possible to assess the performance of each function of damage constructed.

1.3 Data from the study

A household survey conducted in July and August 2016 collected a certain amount of information. This survey was conducted mainly in areas that are frequently flooded in the "Grand Ouaga" area. Data collection was done using questionnaire administered to heads of households. The questionnaire focused on the situation of the respondents to the flood problem, the historical events of flooding (the most drastic event), the water levels reached in the dwellings as well as the estimated value of the damages suffered and the type of housing impacted. In sum, this survey identified the damage caused by floods to housing and associated water levels.

A total of two hundred and forty-three (243) household heads were interviewed on these sites. Pretreatment of the data collected allowed us to finally retain one hundred and ninety (190) households for the realization of this study. Households not considered in this study were those who were not affected by the floods or who no longer remembered the value of the damage or the water level in the dwellings.

2. RESULTS AND DISCUSSION

2.1 Sample partition

In order to minimize the uncertainty factor on the constitutive laws, we proceeded to partition the sample (Table 1). The discriminating factor considered is "the type of building material". On the basis of this criterion, three categories of buildings were selected. Housing in poor material, semi-concrete and concrete. The poor material refers to constructions in raw earth. Semi-concrete refers to the constructions of raw earth with internal plastering and interior cement. Concrete means constructions made of durable materials such as cement bricks and carved laterite blocks.

In addition, there is a high degree of dispersion in housing costs in the flood zones affected by this survey (Table 1). This variability could be explained by the fact that people do not generally comply with building regulations. In fact, each inhabitant builds his dwelling according to his means and very often without the help of a building technician.

Table I: Partition of the study sample

Type of housing	Number	Average cost of housing in FCFA
Poor material	122	624 230 ± 413 869
Semi-concrete	28	662 500± 385 290
Concrete	40	999 250 ± 526 928

Source: Field Survey, August 2016

2.2 Inondation-damage cuves for dwellings

The parameters a, b, k and the coefficient of determination R2 of the damage function of the three (03) types of dwellings were estimated and presented in Table II.

Table II: Curve fitting parameters by dwelling type

Type of housing	a	b	k	R^2
Poor material	0.9207	2.1649	2.8546	0.55
Semi-concrete	1.1356	1.7828	0.9909	0.6367
Concrete	1.9431	3.4437	0.7302	0.9814

Source: Field Survey, August 2016

For dwellings in poor material, the coefficient of determination R^2 obtained is of the order of 55%. This low value of R^2 could be explained by the fact that construction in poor material is not regulated. At equal submersion depth, the damage may differ significantly depending on the quality of the materials used. Figure 2 shows that damage to the structure is observed from submergence depth on the order of 0.2 m and damage rates of 100% are observed for water depths greater than 1 m.

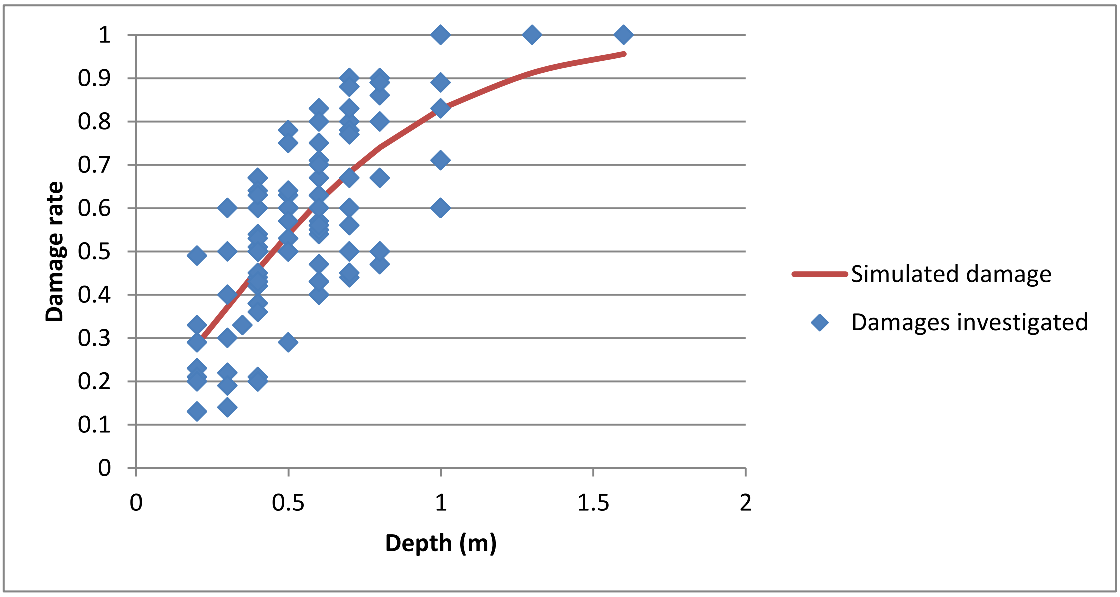

Figure 2: Inundation-damage curve for poor material

For dwellings of semi-concrete type, the coefficient of determination $R^2 = 0.6367$. This means that the height of water observed during the floods accounts for 64% of the damage observed in semi-concrete dwellings. This R^2 value is significantly better than that found for poor material dwellings.

For this category of dwellings, damage to the structure was observed from submergence heights on the order of 0.3 m (Figure 3). The highest value of the damage rate (90%) was observed with a water depth of 2 m.

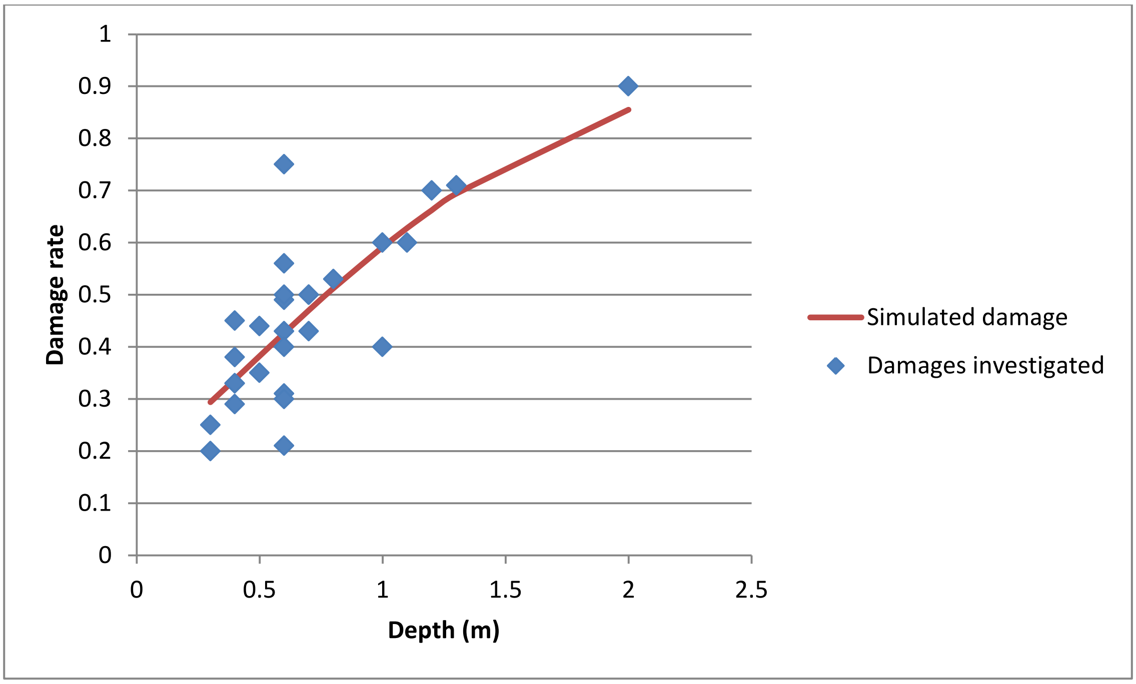

Figure 3: Damage-flooding curve for semi-concrete dwellings (n = 28)

In dwellings in concrete, the coefficient of determination R^2 = 0.9814. This means that the water level observed during the floods accounts for 98% of the damage observed in dwellings. This good result could be explained by the fact that the hard construction is regulated and the construction standards are generally respected.

Here, the damage from the surveys is very close to that obtained from the submergence-damage curve (Figure 4). Damage to the structure was observed from 0.2 m water depth and the highest damage rate value (40%) was observed with a submersion depth of about 1 m.

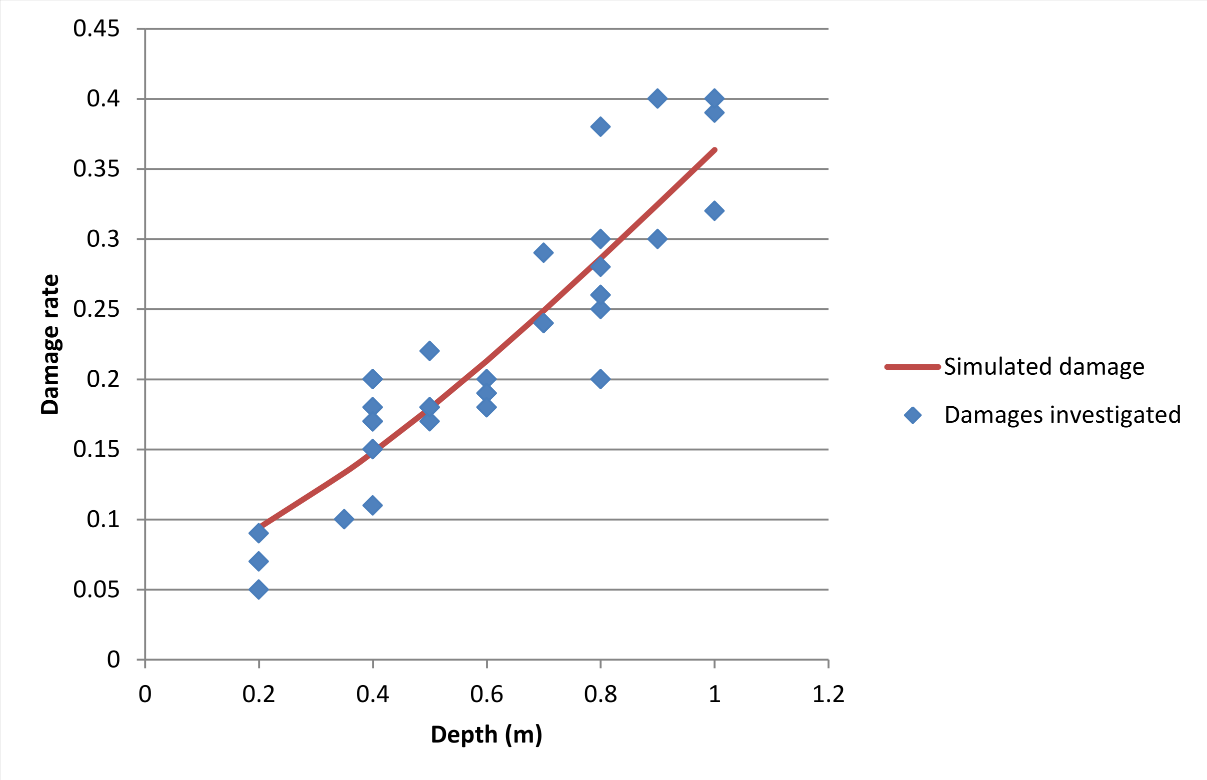

Figure 4: Damage-flooding curve for dwellings in Concrete (n = 40)

2.3 Law of behavior of the rate of damage according to the heights of water

Figure 5 shows the evolution of damage rates according to the water level for the three types of housing considered (poor materiel, semi-concrete and concrete). Damage rates show that dwellings are more resistant to submersion due to flooding. In contrast, poor material dwellings are the most vulnerable to flooding. The water heights that can cause 100% damage to the housing structure are approximately 2 m, 4 m and 5 m respectively for homes in poor material, semi-concrete and concrete.

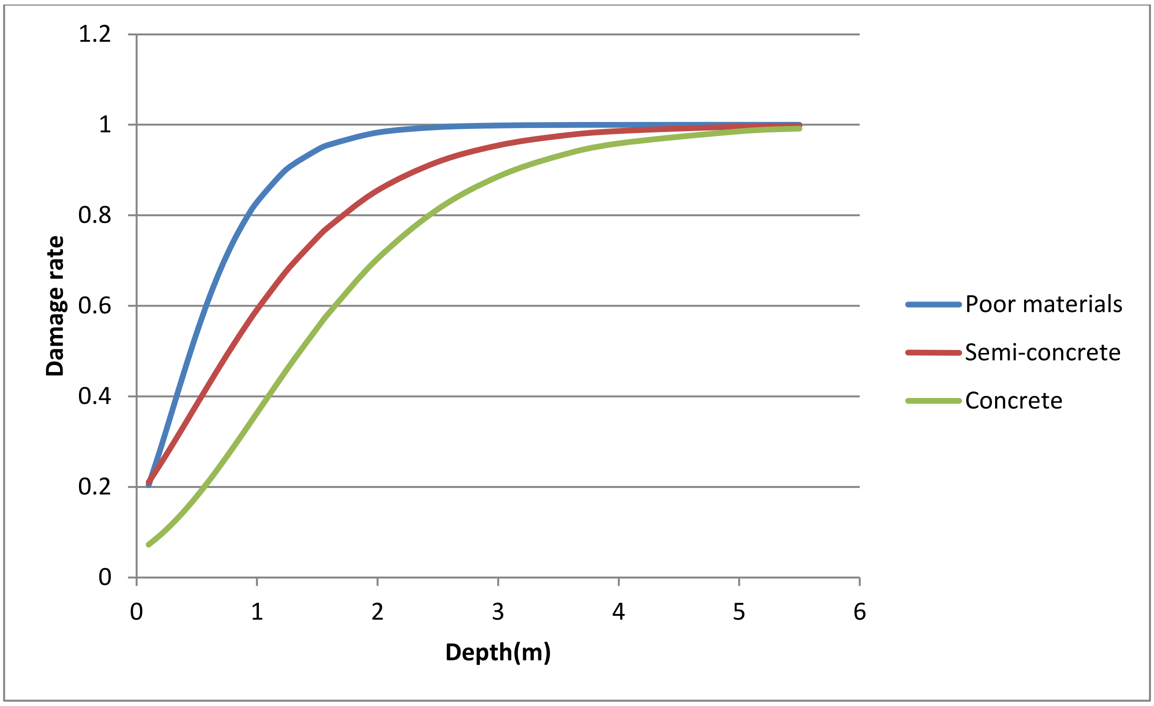

Figure 5: Law of behavior of the rates of damage of the houses according to the depth of submersion

Estimated potential damage to floodplain housing around dams in Ouagadougou

The flood zones around the dams of the city of Ouagadougou are considered by the Ministry of Urban Planning and Housing (MUH) as priority intervention areas. These areas have been identified as priorities in view of their pronounced vulnerability. Indeed, before September 1, 2009, residents of these areas were experiencing floods in the normal winter season. Initiatives had been taken in the direction of relocating these populations without being able to materialize. A census conducted by the Ministry of Urban Planning and Housing (MUH) reported 1,273 dwellings in these areas divided into 814 dwellings, 192 dwellings in semi-hard and 267 dwellings in banco (MUH, 2011). Table 5 shows the estimated costs of potential water-level damage using average house values and established damage functions.

Table III: Estimated potential damage in FCFA for houses in flood zones near the dams of the city of Ouagadougou.

Typology of dwellings	**number of housings**	**Estimation of potential damage according to the height of water (H)**			
		H= 0.5 m	**H= 0.6 m**	**H= 1 m**	**H= 1.5 m**
Concrete	814	144 767 464	171 306 265	300 749 173	499 589 239
Semi-concrete	192	48 748 172	54 008 617	74 520 242	96 511 116
Poor material	267	91 278 190	103 846 653	135 468 619	148 930 742
Total	**1 273**	**284 793 827**	**329 161 537**	**510 738 036**	**745 031 098**

Source: Field Survey, August 2016

Surveys revealed that the average water level observed in dwellings during the flood of September 1, 2009, considered to be the last major flood experienced by the city of Ouagadougou, was of the order of 0.6 m. Estimates of the costs of potential damage show that a flood of the same magnitude would cause damage to the residential structure of the floodplains near the dams estimated at three hundred and twenty-nine million one hundred and sixty one thousand five hundred and thirty-seven francs CFA (329 161 537 FCFA).

This amount, even if it is only indicative, gives an idea of the importance of the exposed issues (the dwellings) to the risk and can guide the choices in terms of public policies of prevention of these floods.

CONCLUSION

This study aimed to construct submersion-damage curves for floodplain dwellings in the "Grand Ouaga" area. It was conducted using data from surveys carried out among residents of flood-prone areas. Three types of dwellings were defined according to the nature of the building material (poor material, semi-concrete and concrete) in order to better capture the variability of the damage according to the maximum submersion depth generally experienced during floods. The water heights that can cause 100% damage to the structure of dwellings are approximately 2 m, 4 m and 5 m respectively for homes in poor material, semi-concrete and concrete.

Predictions of potential flood damage would be of importance to the decision makers involved in managing this extreme phenomenon. The curves developed are intended for estimating housing damage. Although this damage usually accounts for most of the damage caused by floods, it would be interesting to consolidate this study and then extend it to other areas (industrial and commercial). These tools can be used to help communities make decisions regarding the risks involved and, above all, contribute to reducing the risk of flooding. However, the robustness of the curves strongly depends on the quality of the collected data.

REFERENCES

Blin (P.), 2001. Développement d'une nouvelle méthode de cartographie du risque unitaire d'inondation (crue) pour des résidences. Mémoire de maîtrise en Sciences de l'Eau. Université du Québec - INRS-Eau.

CatNat, 2010. Bilan décennal des catastrophes naturelles dans le monde, 11p.

Centre Européen de Prévention des Risques d'Inondation (CEPRI), 2010. Analyse coût/bénéfice. Annexes techniques. Décembre 2010, 78p.

Centre Régional AGRHYMET, 2010. Le Sahel face aux changements climatiques : Enjeux pour un développement durable. Bulletin Mensuel, 42p.

Dantzig (D. V.), 1956. Economic decision problems for flood prevention. Econometrica 24, no. 3: 276-287.

Eleutério (J.), Mosé(R.) et Rozan (A.), 2012. Evaluation des dommages potentiels liés aux inondations : Impact des stratégies utilisées pour modéliser l'aléa inondation et caractériser la vulnérabilité des enjeux sur les résultats des évaluations de dommages potentiels liés aux inondations. Rapport final. Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg (ENGEES). 48p.

Eleuterio (J.), Roz (A.) et Payraudeau (S.), 2009. Sensibilité de l'évaluation des dommages potentiels lies aux inondations. Présenté au 20ème JSE Environnement entre passé et futur :les risques à l'épreuve des savoirs. France. 16p.

Famine Early Warning Systems Network (FEWS-NET). (2014). Analyse Globale de la Vulnérabilité, de la Sécurité Alimentaire et de la Nutrition (AGVSAN). Burkina Faso, 108p.

Genovese (A.), 2006. A methodological approach to land use-based flood damage assessment in urban areas: Prague case study.

Laurent (B.), 2005. Développement de courbes submersion-dommages pour l'habitat résidentiel québécois. Mémoire présenté pour l'obtention du grade de Maître es sciences (M. Sc.). Université du Québec/INRS-ETE, 80 p.

Ledoux (B.) et Hubert (G.), 1999. Synthèse des évaluations socio-économiques des instruments de prévention des inondations, 117 p.

Ministère de l'urbanisme et de l'habitat (MUH), 2011. Mise en œuvre du décret n°2009-793/PRES/PM/MHU/MATD/MEF/MID/MAHRH/MECV DU 19 novembre 2009 portant règlementation des servitudes des canaux primaires d'évacuation des eaux pluviales, des zones inondables inconstructibles et des zones submersibles dans la ville de Ouagadougou. Rapport d'orientations. Burkina Faso, 132p.

Secrétariat Permanent du Conseil National de Secours d'Urgence et de Réduction de Risque et Catastrophes (SP / CONASUR), 2009. Rapport d'activités du SP/CONASUR dans le cadre de la gestion des catastrophes po0ur l'année 2009. Burkina Faso, 36p.