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FLOOD RISK AND VULNERABILITY OF HUMAN SETTLEMENTS IN THE COUFFO WATERSHED AT THE LANTA OUTLET

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ABSTRACT

Flooding is a major risk, particularly in developing countries where the vulnerability of communities is exacerbated by low adaptive capacity and high dependence on their livelihoods. This research analyzes the vulnerability of human settlements to flood risk in the Couffo watershed in Benin.

The collection work was carried out from 215 households following a reasoned choice in 20 villages throughout the Basin. In addition, 45 resource persons were made up of various categories of socio-professional actors. The Spatial Statistics Tools extensions of ArcGis 10.3 were used to characterize the density of human settlements and the determination of their vulnerabilities

The results indicate that the basin is affected by rainfall (20% of localities) and river (nearly 68%) floods. Population expansion and agricultural activities have weakened ecosystems, increasing erosion and the filling of waterways, according to 98% of respondents. The very high-risk areas (Lalo, Tchito, Lon-Agonmey, Lobogo, Akodéha, Bopa) have a high density of establishments, and the high-to-very high-risk areas coincide with a medium to high density. Flooding also affects social cohesion. Although vulnerability varies, no village is spared, illustrating the difficult living conditions in the study area.

Keywords: Risk, Flooding, Vulnerability, Human Settlements, Couffo Basin.

1. INTRODUCTION

Extreme events and the resulting disasters are increasingly at the centre of scientific, political and public concerns. Of the 189 major natural disasters recorded in 2014, 32% were floods (E. Gaume et al., 2016, p. 26). These have caused significant damage around the world, illustrating the high exposure of our societies to this risk. Generally speaking, floods are the most destructive natural hazard globally, due to their frequency and the high exposure and vulnerability of human issues. They are the source of nearly half of the deaths and one third of the economic losses related to natural disasters over the past 50 years (H. Koumassi et al., 2014, p. 5). Over the past two decades, floods have caused an estimated 158,000 deaths and affected more than 2.3 billion people. Although flood mortality has declined since the 1980s, annual economic losses average more than US$23 billion (A.K. JHA et al., 2012, p. 25), representing more than 140% of annual

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U.S. GDP for comparison. Floods are thus considered a major threat to the safety of populations and the economic development of exposed countries (M. Tanguy, 2016, p. 12).

The catastrophic floods of 2010 and 2012 in Benin highlighted the weak capacity of local authorities in terms of risk management. A concrete and targeted approach to climate risk management is needed. In the Couffo watershed, many localities are affected annually by river floods and rainfall flooding, causing significant damage to homes, schools, health centers, roads, markets, places of worship, drinking water and sanitation networks, as well as other public goods and services. This situation increases the vulnerability of populations whose livelihoods are deteriorating, undermining local development. Strengthening flood adaptation strategies in this area is crucial to sustainably reduce its vulnerability to this natural disaster.

1. Presentation of the Couffo catchment area

The Couffo watershed, with an area of about 1680 km², is located in the southwest of Benin and is part of the Mono-Couffo complex, one of the country's four major watersheds. It is located between 6°35' and 7°45' north latitude and between 1°15' and 2°8' east longitude. The choice of this basin is justified by its role as an area of high agricultural production and its sensitivity to the effects of flooding. Figure 1 illustrates the geographical location of the Couffo watershed in Lanta.

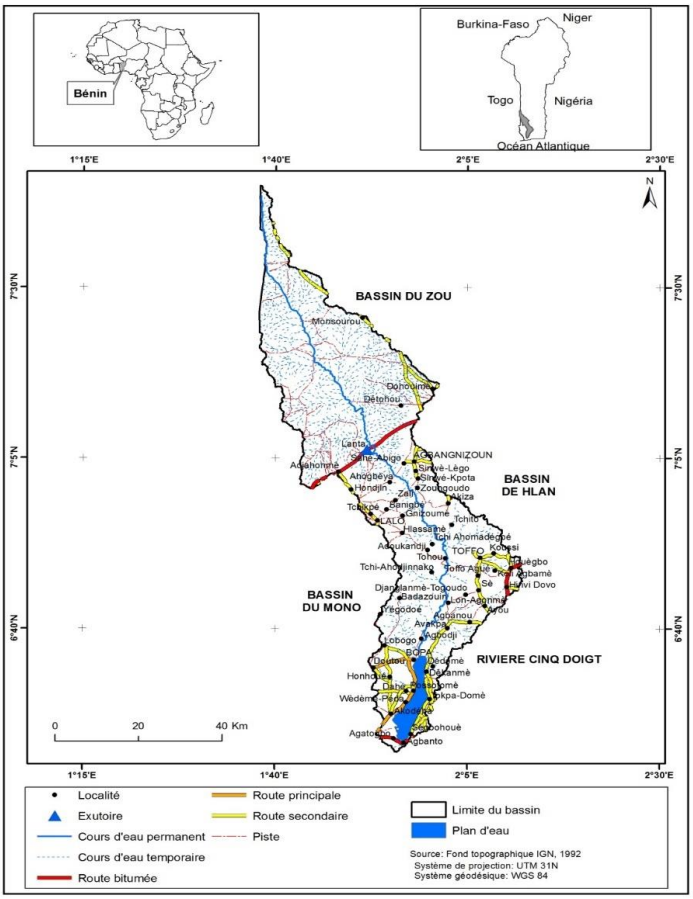

Figure 1: Geographical and administrative situations of the Couffo catchment area

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Administratively, the Couffo watershed (BVC) includes 88 villages spread over 15 municipalities. It is bounded to the north by the Zou basin, to the south by Lake Ahémé (which flows into the Atlantic Ocean), to the east by the Hlan basin and the Five Fingers River, and to the west by the Mono basin.

The relief of the BVC in Lanta is relatively flat, like Benin. The Aplahoué plateau rises to an average of 80 m (Fanou et al., 1997) and has a low undulating relief. To the north of the basin lies the crystalline peneplain, with an average altitude of 200 m.

Hydromorphic soils, whose evolution and classification are linked to the presence and action of water (rainwater, river overflow, rising water table), are subject to periodic waterlogging. Although very fertile, they are flooded seasonally by the floods of the Couffo.

Poorly evolved soils or raw mineral soils, characterized by a low differentiation of horizons, are found in the barrier beaches. They are highly permeable and have a low water retention capacity.

Weakly ferrallitic soils develop on rocks that are sufficiently rich in iron and constitute a well-drained environment. These sandy-clay formations of the Terminal Continental have a clear structure at depth and porous at the surface, linked to intense biological activity. Their permeability and drainage are due to the sands and their good distribution. Fertile but sensitive to anthropogenic degradation, fire and erosion, exundated ferrallitic soils are excellent supports for dense humid forests.

2. METHODOLOGICAL APPROACH

The investigation unit is made up of households, represented by their heads, chosen in a reasoned way to include all strata of the population affected by the floods. A multi-stage sample (areas of economic activity and residence) was used. The selection of interviewees was based on the following non-cumulative criteria:

- be a farmer, at least 40 years old and have 15 years of professional experience;
- have been permanently resident in the area for at least 20 years to provide reliable information on the occurrence, manifestations and most frequent type of flooding in the Couffo catchment area;
- have been the victim of a flood at least once.

Sample size was determined using Schwartz's (2002) statistical protocol (P1). It was calculated with a 95% confidence level and a margin of error of 5%.

$$N = Z\alpha 2.\ PQ / d2$$

With: N = sample size per rounding;
Zα = deviation set at 1.96 corresponding to a 95% confidence level;
P = number of households in the district / number of households in the municipality;
Q = 1 – P and d = margin of error which is equal to 5%.
A total of 215 households were interviewed in 20 villages spread over six communes in the Couffo watershed. The study also included 45 resource persons, consisting of:

- Local elders (from various socio-professional categories), aged 70 and over, whose testimonies have made it possible to trace the origin of flood risks and the most frequent type of flooding in the past.

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- Rural development agents on duty in the various communes of the BVC, whose interviews made it possible to assess the extent of the damage caused by the floods on human settlements, particularly agriculture.

2.1. Method for determining the density of human settlements

The determination of the density of human settlements began with their identification using archival documents and field data. The categories of human settlements identified are housing, the road network, production sites and socio-community infrastructure. The data for each category come from INSTaD Benin and have been supplemented by field surveys.

The spatial distribution of each category was analyzed using the Spatial Statistics Tools toolbox in ArcGis 10.3. The overall density of human settlements was obtained by a linear combination of cartographic information on dwellings, road network, production sites and socio-community infrastructure, with a unit weighting for each factor. The pixel weights of the resulting image were then classified into three density levels (Low, Medium and High) according to the Jenk natural break method. The density (km^2) of each modality was calculated.

2.2. Methodology for determining socio-economic vulnerability

Socio-economic vulnerability is based on the analysis of the structural factors that make communities susceptible to damage from external risks (Brooks cited by Koumassi, 2014). This involves the collection of information about the study area, including stakeholders (vulnerable groups), ecosystem services and vulnerability factors. The identification of the sectors of activity affected by hydro-climatic risks was carried out by brainstorming, aimed at identifying the activities perceived by local populations and actors as having been affected or highly exposed to climatic hazards. For each economic activity present in the locality, the populations were asked about their exposure to one or more climatic factors. At the end of this process, the sectors of activity most vulnerable to hydro-climatic risks were selected.

3. RESULTS

3.1. Type of flooding in the Couffo catchment area

The Couffo catchment area is mainly subject to two types of flooding. Rainwater flooding is the result of the accumulation of runoff water following heavy rainfall or prolonged rainfall. The relief, the nature of the soil as well as the use and occupation of the land exacerbate the damage of these floods. River flooding, on the other hand, is due to the overflow of rivers during flood periods. In order to visualize the type of flooding observed in the different villages, a Correspondence Factor Analysis (CFA) was carried out (Figure 2). For this analysis, only the F1 axis, whose eigenvalue is higher than those of the others according to the relative criterion, was retained. This axis concentrates all the inertia, and therefore most of the information in the point clouds.

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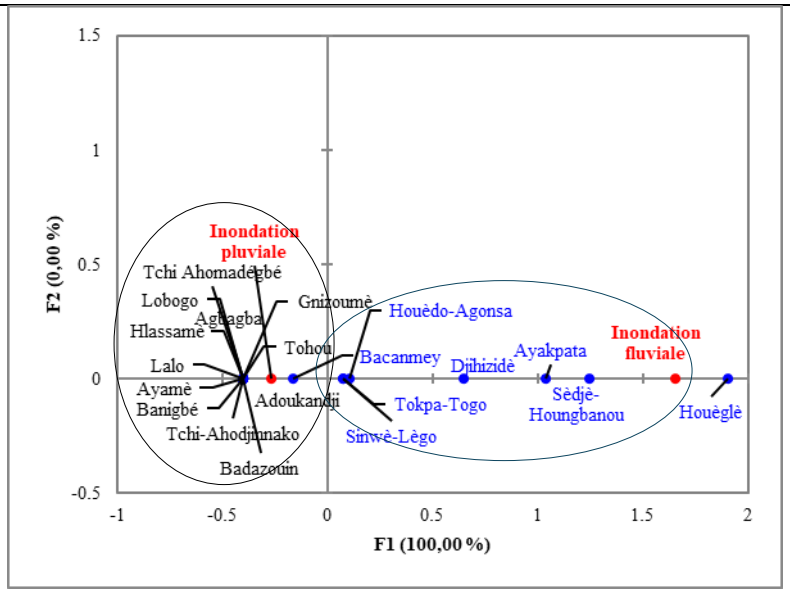

Figure 2: Distribution of villages according to the type of flood that occurred

Data sources: *Fieldwork, November 2021*

Analysis of the figure reveals that all projected variables are correlated with the F1 factor, with their coordinates on the F2 factor being almost zero. This analysis reveals two main types of flooding, thus distinguishing two major groups of villages. Within the BVC, the nature of the floods varies from one locality to another. The G1 group, representing 60% of the villages studied and mainly located in the communes of Lalo, Bopa and Allada (often in the middle depression), is only affected by rainfed flooding. The low water-holding capacity of the soils in these villages makes them vulnerable to heavy rainfall and waterlogging. Only 20% of the villages surveyed, located in the communes of Toffo, Allada, Zogbodomey and Agbangnizoun, are frequently victims of both types of flooding, making them the most exposed to river flooding. The vulnerability of human settlements is clearly high in all G2 villages. The data indicate that some establishments in this category suffer both types of flooding in particularly rainy years, placing the populations in a critical situation. Overall, rainwater flooding is more frequent in the area than river flooding, which occurs in years with exceptional rainfall.

3.2. Vulnerability of human settlements to flooding

The Couffo, the main watercourse in the basin, receives the contribution of several tributaries around which the populations have developed their livelihoods. Over the years, population expansion and mainly agricultural activities have, according to 98% of the respondents, weakened riparian ecosystems by accentuating erosion and causing the filling of watercourses. This situation has increased the flood area. Homes, fields and road infrastructure are the most affected settlements in the basin (Figure 3).

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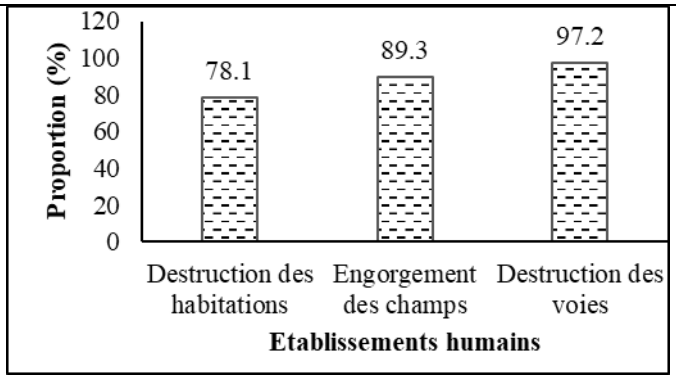

Figure 3: Human settlements vulnerable to flooding in the basin

Source: *Field surveys, November 2021*

Analysis of the figure reveals that 78.1% of respondents identified the destruction of homes as a consequence of the flooding in their localities. Waterlogging of fields is also cited as a major effect, regularly affecting 89.3% of respondents in the study area. In addition, 97.2% of respondents reported that roads were impassable due to these disasters. These three types of human settlements are the most vulnerable to flooding in the basin, although this situation varies by locality (Figure 4).

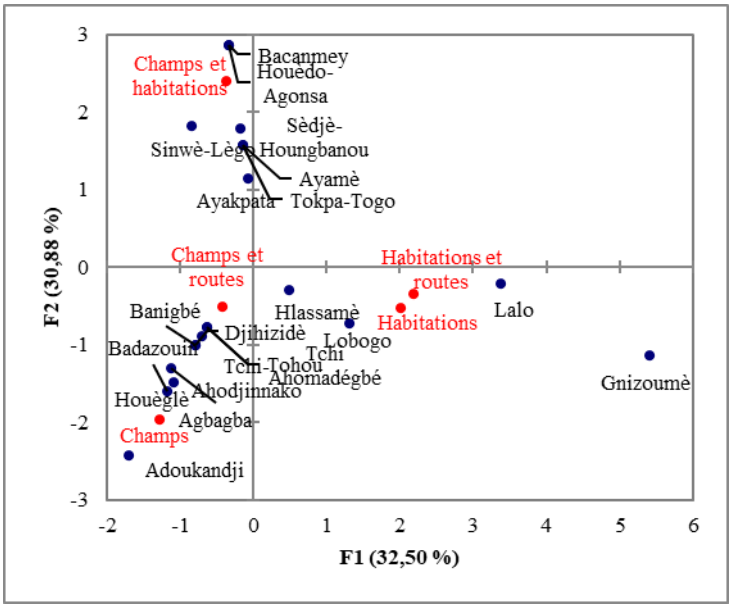

Figure 4: Human settlements vulnerable to flooding by village

Data source: *Field survey, November 2018*

The PCA matrix reveals a total inertia of 63.38%, with 32.5% for the F1 factor and 30.88% for the F2 factor, a sufficient proportion to establish links between the variables and the observations. Analysis of the figure indicates vulnerability of fields and homes to flooding in

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localities such as Bacanmey, Houédo-Agonsa, Sinwé-Lègo, Sèdjè-Houngbanou, Ayamè, Ayakata and Tokpa-Togo. In Banigbé, Badazouin and Djihizidè, it is the fields and roads that are more vulnerable. The fields are the most affected establishments in Houèglè, Ahodjinnako, Agbagba and Adoukandji. Conversely, in Hlassamè, Lobogo, Tchi, Tohou, Ahomadégbé, Gnizoumè and Lalo, homes and roads are the most vulnerable. These results highlight that no village is spared from the vulnerability of human settlements to flooding, although this vulnerability varies from locality to locality, reflecting the difficult living conditions encountered in the study area.

Socio-economic vulnerability is defined as a state intrinsic to a system before the occurrence of a damaging event (Allen, 2003). It manifests itself in factors that limit or increase harm, or that influence the ability of individuals, groups, institutions, or societies to cope with disruption. Stemming from the study of the structural factors exposing communities to external risks (Allen, 2003), this conception emphasizes the inherent vulnerability of communities, regardless of hazards. Figure 5 illustrates the different levels of vulnerability of institutions in the search area.

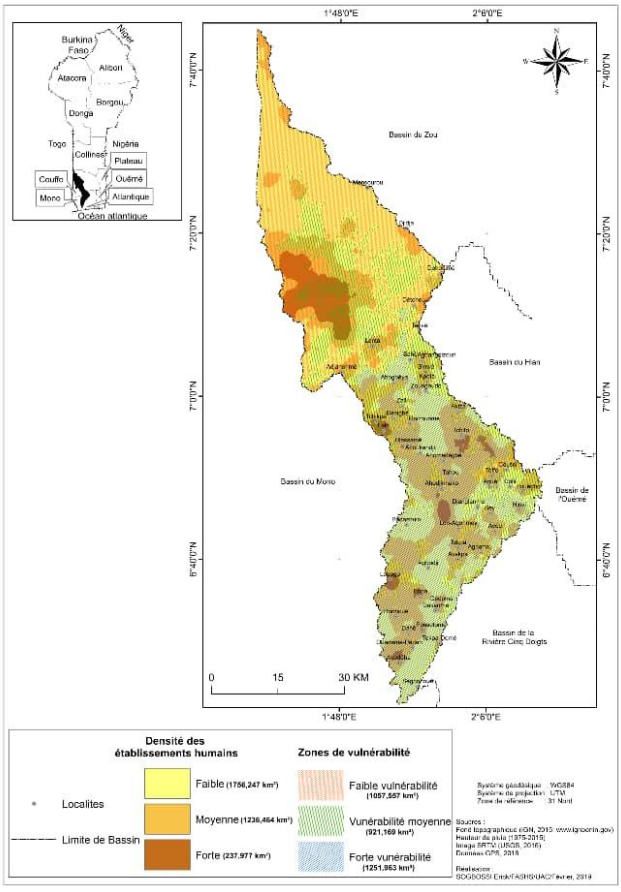

Figure 5: Human settlements density in the localities of the Couffo basin

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Localities such as Colli, Coussi, Zoungoudo, Sahè, Tanvè, Zalli, Agué, Djanglanmè and Dékanmè have a low density of human settlements, which makes them less vulnerable to flooding in the Couffo basin in Lanta. Medium-density settlements in localities such as Sègbohouè, Akodéha, Ouèdèmè-Pédah, Dahè, Possotomè, Tokpa-Domè, Honhoué, Badazouin, Agbodji, Toffo, Adoukandji, Hlassamè, Akiza, Kpota, Sinwé and Lanta are moderately vulnerable to flooding. Finally, localities with a high density of human settlements are highly vulnerable to flooding in the Couffo basin in Lanta. In general, the vulnerability of human settlements increases with their density. In the Couffo catchment area, there are two main levels of vulnerability: medium and high.

A concentration of human settlements is observed in areas at risk of flooding within the BVC. The superimposition of these two elements makes it possible to assess the level of vulnerability in the sector, bearing in mind that the density of settlements is not uniform in the Couffo catchment area (Figure 6).

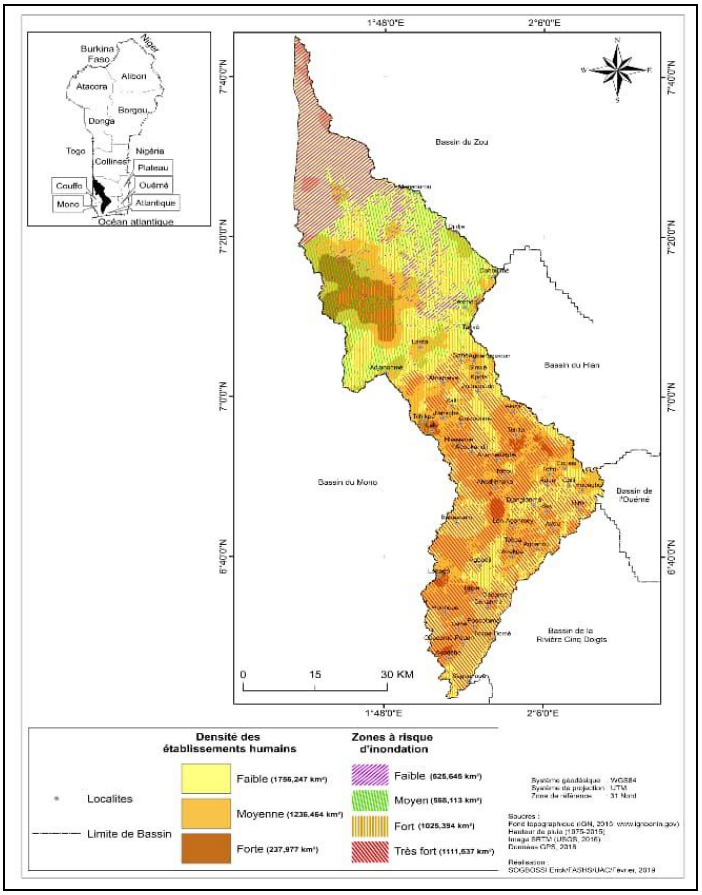

Figure 6 : Overlay of human settlements with flood-prone areas

A high density of human settlements is observed in areas at very high risk of flooding, including Lalo, Tchito, Lon-Agonmey, Lobogo, Akodéha and Bopa. Areas at high and very high risk of

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flooding coincide with areas with medium to high human settlements density. The occurrence of flooding in these areas would have serious consequences for the establishments located there.

In addition, flooding affects community life by eroding solidarity and the social fabric. They lead to mass migration and a loss of cultural values, making community work impossible. About 72.8% of respondents say they left their homes for safe places (market, school, church, town hall, etc.) during the floods. The 2010 floods caused three deaths in Tohou. After the floods, the resumption of economic activities is difficult, leading to the impoverishment of households, a loss of trust and mutual mistrust within communities, as well as an exacerbation of inter- and extra-community conflicts.

4. DISCUSSION

The Couffo watershed is an area particularly exposed to the risk of flooding, an often devastating hazard affecting thousands of people. Flooding is a major threat to human settlements in this basin, as in many others, exacerbated by climate change and often inadequate infrastructure. According to Blaikie et al. (1994), the vulnerability of human settlements refers to their susceptibility to damage in the event of flooding. In West Africa, floods are leading to loss of life and mass displacement, generating humanitarian crises (IDMC, 2021). This vulnerability is influenced by socio-economic, physical and institutional factors. Cutter et al. (2003) point out that poor and marginalized populations are often the most vulnerable because of their limited access to resources and protection. Jha et al. (2012) add that the location of settlements in flood-prone areas, the quality of construction, and urban density increase this vulnerability. Di Baldassarre et al. (2017) indicate that climate change is intensifying flood risks in West Africa, with an increase in extreme rainfall and a more intense rainy season, insisting on the consideration of climate projections in risk management. Niang et al. (2014) highlight ecosystem degradation, including deforestation and desertification, as key drivers of increased vulnerability, recommending ecological restoration measures. Satterthwaite et al. (2020) discuss the impact of poverty and rapid urbanization on vulnerability, noting that poor populations are often forced to move to at-risk areas due to a lack of affordable alternatives.

In neighbouring Nigeria, erosion has resulted in the loss of 250 to 500 m² of sediment in some areas of Bar Beach (Folorunsho, 2004). African states, faced with these hazards, have financial difficulties in coping with them, because, as Defossez (2009) points out, the organization of flood control depends on the resources of the affected societies. Adaptation represents a high cost for these countries, which explains why some are resigned. Examples such as the rehabilitation of the green belt in Nouakchott (Mauritania) for US$4184/ha (2000-2007), the artificial feeding of a beach in The Gambia that resulted in a loss of half of the sediment in two years (Fall, 2011), and the reclamation of Labadi beach in Ghana at a cost of US$435/m (Niang et al., 2012) illustrate these financial challenges.

The year 2005, considered disastrous, marked the whole world. The 4th IPCC report (Lepage et al., 2007) identifies West Africa, including the study area, as one of the most vulnerable regions to climate change. This vulnerability is exacerbated by development challenges such as inadequate infrastructure and technology, ecosystem degradation, complex disasters, and conflict (Ahouangan et al., 2014). These findings are in line with the results of this study, where the

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human settlements considered (fields, houses, school and road infrastructure) present a high level of vulnerability, in particular because of the characteristics of the houses.

5. CONCLUSION

In the Couffo watershed, human settlements are generally vulnerable to flooding, particularly traditional dwellings with precarious foundations, of which only 27.9% are made of hard bricks. These houses are subject to destruction and flooding (duration of submersion: one to more than two months), resulting in the loss of food stocks. Flooding also degrades rural roads and floods schools.

The fields represent the main settlements of the most vulnerable populations. Their submersion (one to four weeks) causes significant agricultural losses (about 834,730 CFA francs per farmer). Faced with this vulnerability, populations are developing adaptation strategies.

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