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GIS-Based Mapping of Flood Vulnerability and Risk in the Bénin Niger River Valley

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ABSTRACT

In recent decades, flood disaster has been occurring frequently in West Africa. Located in the heart of West Africa, the Niger River Basin has not been spared the flood hazard that is threatening human security in the region. Those living in flood affected areas face the risk of severe damage to their infrastructure, the loss of their livelihood as well as a substantial threat of injury and death. These hazards can hamper efforts to escape poverty and set back development gains. Despite the threat, there is very scant research documenting flood risk. Without flood risk analysis, opportunities to reduce vulnerability could be missed and the impact of development work may be undermined. With these concerns in mind, this study addresses flood vulnerability and risk in the Bénin Niger River Valley including the two municipalities Karimama and Malanville. A GIS-based mapping and theory-driven indicator approach was applied. The assessment revealed that almost 90 % of the district is located in a flood hazard footprint and is consequently exposed to a high flood risk. However the municipalities are not exposed to the same degree of flood risk due to their different degrees of vulnerability. The vulnerability indicators chosen in the framework of this study show that the municipality of Karimama is more vulnerable than the municipality of Malanville. This discrepancy is due to higher poverty rates and weaker pre-existing physical, social, economic and environmental vulnerability conditions present in Karimama. The risk assessment revealed that 70% of the districts in the area are at high flood risk. In view of potential extreme climate events, we assert that there is an urgent need to have high resolution data in order to deepen research about the flood risk in the Niger River basin.

Keywords: Bénin Niger River, Flood, Vulnerability, Risk, GIS-Based mapping

1. Introduction

Since the 1970s, West African communities have been experiencing the impact of hydrological hazards on their livelihood (Oyerinde et al., 2014). Despite the general decrease in annual rainfall in West Africa from the 1960s to the 1990s (CEDEAO-ClubSahel/OCDE/CILSS, 2008; Descroix et al., 2013; Okpara et al., 2013; Ly et al., 2013), there has been a partial rainfall resumption in the region since the turn of the century. (New et al., 2006; Aich et al., 2014). This increase has been observed on the Guinean Coast (AMCEN, 2011) and in the West African Sahel (Tschakert et al., 2010; Sarr, 2011). Floods frequently affect socio-ecological systems and the damage can include: death, destructions of farms and socioeconomic infrastructure, disruption of socioeconomic activities, losses of properties and disease, etc.

According to recent climate projections, heavy precipitation is projected to increase substantially in West Africa (IPCC, 2013). The projected increase in the frequency and intensity of heavy precipitation may increase the probability of flood risk.

The Niger River basin, is also experiencing flood events. Goulden and Few (2011) state that since there was a partial rainfall recovery in the late 20th century, floods associated with intense rainfall became more common in the region from 1995 to 2010. Floods have become the most common natural disaster in the Niger River Basin (Okpara et al., 2013), with major impacts on human security including damage to production, communication systems as well as people's livelihood and health.

In the Bénin Niger River Valley, similar problems were observed. This region experienced significant socio-economic damages and losses of life due to flood events. In 2010, about 14,911 people were affected (WB/UNDP, 2011). In 2012, eight deaths were reported, more than 2,888 homes affected with at least 43,857 victims and 23,640 ha of cropland (rice, maize, sorghum, pearl millet, and vegetable) were destroyed (www.foodsecuritycluster.net). In 2013, more than 21,500 ha of crops were destroyed, with 9,200 households affected (BAD, 2014). The inhabitant living within the area, in 2013 estimated about 234,681 (INSAE, 2013), regularly suffer from floods effects.

Research activities have been carried out in the Niger River basin at different time scales and spaces. But most hydrological studies have focused on streamflow and runoff processes. Research studies about flood risk in the basin have been insufficient (Okpara et al., 2013; Aich et al., 2014), despite the threats they pose to human security Information concerning the Benin portion of the river valley has been particularly lacking. There is no flood risk assessment in the Bénin Niger River. Therefore flood risk analysis in the region is still an area of investigation. This underscores the justification of the present study.

Various studies (Ezemonye and Emeribe, 2011; Kebede, 2012; Abah, 2013; Isma'il and Saanyol, 2013; ICIMOD and UNESCO, 2007) have shown that Geographic Information Systeme (GIS) is a valuable tool for flood risk mapping. Alkema (2004) argues that Remote Sensing and GIS techniques are vital for flood risk assessment studies, especially in areas where data is scarce or outdated. The GIS could be used for flood risk analysis and mapping in Bénin Niger River Basin which is located in a remote area, where there is less published information and the probability to have updated and reliable data is weak. It is in this context that this paper seeks to contribute to the existing body of knowledge by applying GIS-based method to assess the flood vulnerability and risk profile of the Bénin portion of the Niger River Basin.

2. Study area

Located in the most northerly part of Bénin in the Alibori department, the research area is a region of the middle Niger River basin in the Sahelo-Sudanian zone, between the parallels 11°5' and 12°25' latitude north and meridians 2°43' and 3°40' longitude east (Figure 1). It has an average annual rainfall of between 700 and 900 mm. The area, called "Bénin Niger River Valley", expanding from the extreme north-west to extreme north-east, comprises the municipalities of Karimama and Malanville with ten districts (Karimama, Birni Lafia, Monsey, Kompa, Bogo-Bogo, Malanville, Garou, Guéné, Madécali and Toumboutou) with an area of about 9118 km2 and a population about 234,681 (INSAE, 2013). It is bordered by the Niger River Course in the north, the municipalities of Banikoara, Kandi and Ségbana in the south, the Republics of Burkina-Faso and Niger in the west and the Federal Republic of Nigeria in the east.

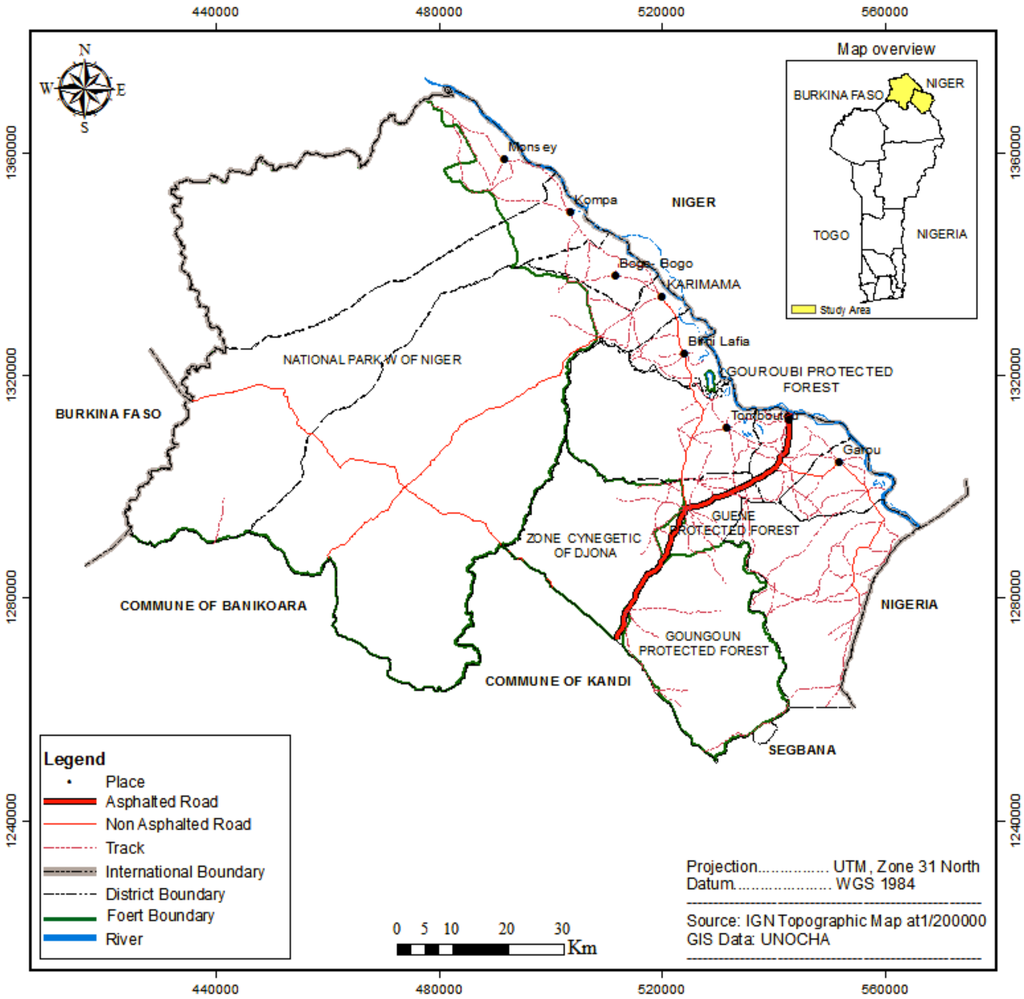

Figure 1: Benin Niger River Valley

3. Methodology

3.1 Dataset and sources

The spatial distribution of the intensity level of the flood hazard index layer for Benin at 1km, was extracted from the first volume (2nd edition) of the World Health Organization (WHO) e-atlas of disaster risk for the African Regions. The 30 meters SRTM Digital Elevation Model (DEM) downloaded from USGS website has been used to express the elevation and the orientation of the slope of the area. The administrative boundaries and road network layers are accessible from the Humanitarian Response Info website while the landcover, the hydrography layers and the environmental indicators have been obtained from the “Centre National de Télédétection et de Cartographie” of Benin. Existing census data (socio-economic, physical) (Table 3) was collected from “Institut National de la Statistique et de l’Analyse Économique”. Field surveys were carried out in order to obtain more detailed information about the flood exposure of the communities and to complete vulnerability indicators chosen from the census data. Additionally, articles, theses, official government documents and reports were consulted.

Table 1: Available data

Content	Format	Sources
Spatial distribution of the intensity level of flood hazard for the Bénin at 1km Resolution.	Raster file	The WHO e-Atlas of disaster risk for the African Region - Volume 1. Exposure to natural hazards (version 2.0)
SRTM 30 m DEM.	Raster file	United State Geological Survey
Landcover and hydrography layers.	Polygon shape and raster file	Centre National de Télédétection et de Cartographie (CENATEL, Bénin).
Road network, administrative boundaries.	Polygon shape	Humanitarian Response Info / United Nations Office for the Coordination of Humanitarian Affairs
Census data (Socio-economic indicators values)	Pre-processed, in table format	Institut National de la Statistique et de l'Analyse Économique (INSAE, Bénin).

3.2 Hazard assessment

Already existing "spatial distribution of the intensity level of flood hazard for the Bénin" at 1km extracted from the WHO e-Atlas of disaster risk for the African Region was used to generate the flood hazard distribution map. The complete description of the flood hazard modelling of the "WHO e-atlas of disaster risk, volume 1: exposure to natural hazards, version 2.0" is beyond the scope of this study, but can be found in El Morjani (2011). However, it should be noted that the method uses statistical specializing of the distribution of intensity of flood hazard, which combines historical flood frequency and distribution of flood causal factors (Land use and land cover, elevation, soil type and texture, lithology, flow accumulation volume, distance from the flow accumulation path and precipitation) in order to predict areas particularly vulnerable to floods. To obtain our flood hazard index distribution map, the study area polygon shapefile was added to the Bénin flood intensity level raster format and extracted by mask function under a spatial analyst tool in ArcGIS 10.1. The flood hazard index distribution map obtained was reclassified into two intensity levels from 1 to 2 using a natural breaks scheme and rescaled from 0 to 1. 0, indicates the lowest likelihood for a flood to occur whilst the highest probability is 1 (figure 2 (a)).

3.3 Exposure Assessment

IPCC (2012) conceptualizes exposure as "the presence of human and ecosystem tangible and intangible assets, activities and services in areas affected by the hazard". This study follows the same idea and defines exposure as elements at risk (people and assets) of being damaged by a flood event. As the landcover layer contains elements at risk, the exposure assessment involves intersecting the hazard layer on the standardized landcover layer in ArcGIS 10.1 (figure 3 (a)). However, in order to later create the risk map, each of the original landcover determinants was reclassified into ordinal values classes from 1 to 4 according to their relative importance in causing flood. This method was based on the best practices based on literature review and the authors' knowledge of the study area. Linear scale transformation method were applied to normalize the reclassified values (table 2).

3.3 Vulnerability Assessment

The method used in this study, follows an indicator-based approach where vulnerability is seen as physical, social, economic, environmental characteristics and conditions that make people or communities susceptible to the damaging effects of flood. This form of vulnerability assessment has been recognized internationally and is stressed in the Hyogo Framework for Action (Birkmann, 2006). Several studies (Feteke, 2010; Müller, Reiter and Weiland, 2011; Lundgren and Jonsson, 2012; Balica, 2012) have similarly applied indicators for flood vulnerability assessment.

Table 2: Re-classification of landcover determinants

Original Landcover classification		Re-classified Landcover	Normalized
Numbers	**Determinants**	**Values**	**Values**
13.00000	River	1	0.25
6.00000	Wetlands	1	
1.00000	Dense forest	2	0.5
2.00000	Gallery forest	2	
3.00000	Wooded savannah	3	0.75
4.00000	Arboreous savannah	3	
7.00000	Plantation	3	
10.00000	Mosaic of culture and fallow	3	
9.00000	Bare soil	4	1
8.00000	Rocky surface	4	
12.00000	Built-up areas	4	

When selecting indicators (table 3), the deductive approach was applied, in which the best possible physical, social, economic and environmental vulnerability indicators are identified based on the existing available data and their relevance through a scientific literature review of vulnerability theories. At that point, vulnerability indicators were normalized from 0 to 1 using the functional relationship between variables and indicators developed by UNDP's Human Development Index (HDI) in 2006. This method for normalization was chosen because it does not simply normalize variables and ignore the functional relation between variables and indicators. When the variables have a positive functional relationship with vulnerability, the normalization is done using the formula:

$$Vij = (Xij - MinXi) / (MaxXi - MinXi) \qquad (1)$$

When the variables have negative functional relationship with vulnerability, the normalization is done using the formula:

$$Vij = (MaxXi - Xij) / (MaxXi - MinXi) \qquad (2)$$

Where:

- Vij stands for the standardized vulnerability score with regard to vulnerability component (i), for municipality (j);
- Xij stands for the observed value of the same component for the same municipality;
- MaxXi and MinXi stand for the maximum and minimum value of the observed range of values of the same component, for all settlement of the index.

After normalization, the average index (AI) for each source of vulnerability is constructed by using equal weights methods (table 4). Each index is obtained by averaging the variable within each component of vulnerability following the formula:

$$\overline{AI} = \frac{1}{N}\sum_{i=1}^{n} X_i, \quad (3)$$

$\overline{AI}$ being the average index of each source of vulnerability, $\mathbf{N}$ = the sum of the index and $\mathbf{X_i}$ = the value of the index.

Table 3: Vulnerability indicators used and their relevance

Vulnerability Components	Indicators	Measures	Relations	Relevances
Physical	Material of which the building is made	Poor building material. Material of wall other than brick.	+	Determines the physical fragility towards flood events and indicates the resistance to damage and also the social status. People living in poor-quality housing, cannot recover quickly (Müller et al., 2011).
	Material of which the roof is made	Building with poor roof material. Houses roof in straw	+	
	Material of which the floor is made	Floor with poor floor material. Floor other than cement.	+	
	Water Network density	Percentage of area drained by water	+	High density of water supply network will increase the risk to be flooded. Wetland areas are more prone to flooding (Peck et al., 2007).
Social	People density	Population density	+	There is a high level of exposure to a given hazard if population is concentrated. The higher the population density, the higher the vulnerability (Kumpulainen, 2006; Balica, 2007).
	Age group	0 – 14 years and 60 years+	+	The young and the elderly are more vulnerable to natural hazards both because of their physical condition and their financial dependence. Physical fragility and dependency of very young and very old people (Müller et al., 2011; Fereke, 2010).

	Gender	Female	+	Women are generally described as more vulnerable to natural hazards than men because of their stronger involvement in family life, sector-specific jobs and lower wages (Müller et al., 2011; UN/ISDR, 2006; Fereke, 2010).
	Poverty level	People spending less than 1USD/day	+	Poverty affects people's ability to protect themselves and their assets, as well as their ability to live in areas having less exposure to risk. poor people are the most severely affected by all natural disasters (UN/ISDR, 2006)
	Literacy level	Adult literacy rate	–	Measuring people's ability to understand and gain information. The presumption is that people with a low educational level do not find, seek or understand information concerning risks as well as others, and are therefore vulnerable (Müller et al.,2011; Kumpulainen, 2006).
	Average people per health workers	Number of nurses per 5000 inhabitants	–	Less medical infrastructure and health care, higher vulnerability (IASC, 2012).
Economic	Income level	Income level	+	The lower the income, the higher the vulnerability. Low income people lack financial resources to recover resource (Hebb and Mortsch, 2007).
	Unemployment	Unemployment rate	+	Unemployed individuals may not have money to protect themselves (Balica, 2007; Kuhlicke et al., 2011).

	Household Expenditure per capita	Expenditure per capita	+	Low expenditure increases, can cause vulnerability to increase.
Environmental	Forest area	Area covered with forest	–	Areas with special natural features can be considered vulnerable because they are unique and possibly home to rare species of flora of fauna (Kumpulainen, 2006).
	Protected area	Protected forest area	–	Decrease the magnitude and the impact of the flood hazard. (Kumpulainen, 2006).
	Degraded land	Urban area	+	Degraded Environment decreases livelihood resilience and can lead to an increase in exposure (Renaud, 2013).

Table 4: Normalize vulnerability index

	Variables values (%)		**Normalized values**	
Physical measures	**Karimama**	**Malanville**	**Karimama**	**Malanville**
Poor building material. Wall material other than brick.	97.3	92	1	0
Building with poor roof material. Houses roof in straw.	62.6	35	1	0
Floor with poor floor material. Floor other than cement.	96	67.9	1	0
Percentage of area drained by water.	4.34	3.24	1	0
$\overline{AI}$			**1**	**0**
Social measures				
Population leaving in flood prone area	11	56	0	1
0 - 14 years and 60 years +	51.6	50.9	1	0
Female	50	50.2	0	1
People spending less than 1USD/day	83.3	71.2	1	0
Adult literacy rate	5.6	14.1	1	0
Number of nurses per 5000 inhabitants	45	86	1	0
$\overline{AI}$			**0.7**	**0.3**
Economic measures				
Low Income levels	53.7	42.5	1	0
Unemployment rate	73.9	54	1	0
Households with the poorest expenditures per capita	73	52	1	0

$\overline{AI}$			**1**	**0**
Environmental measures				
Area covered with forest	90.2	73.6	0	1
Protected forest area	86.1	41.4	0	1
Urban area	0.1	0.8	0	1
$\overline{AI}$			**0**	**1**

Data sources: Field surveys, INSAE (2011), INSAE (2013), WFP (2013).
(+) = Increase in vulnerability, (−) = Decrease in vulnerability

The overall vulnerability index (Vul_i^0) for each city is obtained by averaging the four values of each component of vulnerability using the formula:

$$Vul_i^0 = (Vul_i^{Phy} + Vul_i^{Soc} + Vul_i^{Eco} + Vul_i^{Env})/4 \qquad (4)$$

Where: $Vul_i^{Phy} + Vul_i^{Soc} + Vul_i^{Eco} + Vul_i^{Env}$ are respectively the average values of each source of physical vulnerability index (Vul_i^{Phy}), social vulnerability index (Vul_i^{Soc}), economic vulnerability index (Vul_i^{Eco}), and environmental vulnerability index (Vul_i^{Env}) for the municipality (i). Once the overall vulnerability is calculated, they were linked as attributes to the vector polygon shape of each municipality and then converted into a raster format to generate a vulnerability map.

3.4. Risk assessment

Because risks have different components, the variety of methods for assessing each component of risk is reflected on the risk assessment approach. Among the different methods available, the GIS-base mapping method is “the most recent method and it holds a lot of promises as it is capable of combining all the known techniques and parameters” (Ologunorisa and Abawua, 2005). This paper applied the same method and the risk is seen here as function of hazard, exposure and vulnerability. It is assessed through the formula:

$$Risk = Hazard \times Exposure \times Vulnerability \qquad (5)$$

Table 5: Overall vulnerability index

Administrative units	Vulnerability components				Vulnerability index	Rank
	Physical	Social	Economic	Environmental		
Karimama	1	0.7	1	0	0.7	1
Malanville	0	0.3	0	1	0.3	2

In this study, the free standardized layers (hazard, exposure and vulnerability) ranged from 0 to 1 were weighted equally important. Therefore, 1/3 was assigned as weight for each layer and aggregated through the weighted linear combination method using a raster calculator under spatial analyst tools of ArcGIS 10.1. The resulted map was reclassified into two classes from 0 to 1, indicating respectively low and high risk.

4. Results and discussion

Figure 2 (a) below shows the output of the hazard assessment. The map indicates that 90% of the districts of Bénin Niger River Valley are located in the flood hazard pathway, except a part of the District of Guéné.

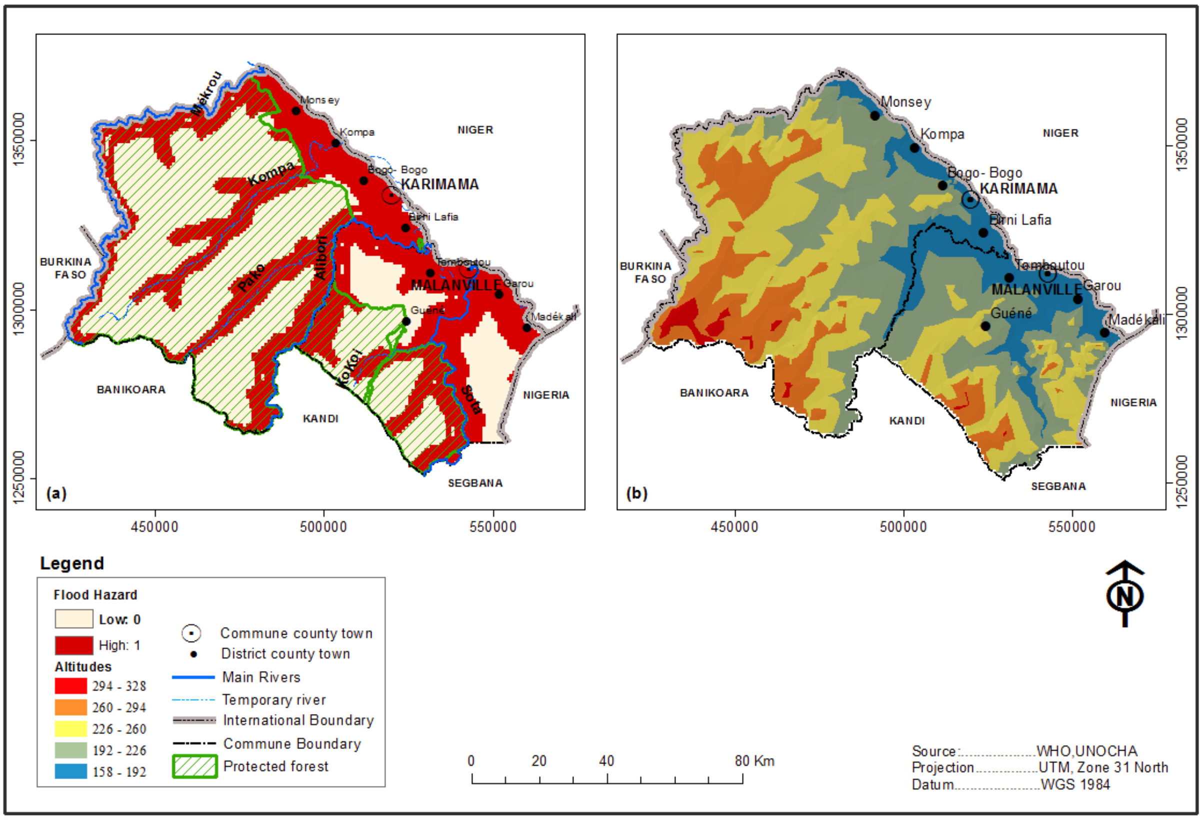

Figure 2: (a) Flood hazard, (**b**) DEM of the Bénin Niger River Valley

A combined analysis of the Digital Elevation Model (figure 2 (b)) and the flood hazard map reveals that the hazardous areas are the areas at low elevation alongside the Niger River as well as the areas that border the beds streams of its tributaries Mékrou, Sota and Alibori. As hazardous areas are low-lying areas and closer to the rivers network, it can be deduced that the magnitude of the flood hazard of a given area is a function of both the distance to the river and the elevation of the area in question. The output of element at exposure in the figure 3 (a) below shows that 75% of the study area is covered by protected forest. Almost 70% of households in the Benin Niger River Valley are highly exposed and settlement areas are highly exposed to flood hazard except from some part of Guéné. The field surveys and the resulting analyses reveales that the population is largely constrained to settling in the river flood plain due to the fact that most arable land is found along the river and the remaining area is largely made up of protected forests. It follows that an increase in settlement and development activities along the rivers flow path will therefore result in a high exposure to flood hazard.

Table 4 illustrates the normalized vulnerability index and table 5 summarizes the overall vulnerability index. With regards to the considered indicators, the normalized vulnerability index indicates that the municipality of Karimama is more vulnerable physically, socially and economically than the municipality of Malanville. However, when looking at the environmental vulnerability index (table 4), the Malanville municipality is more vulnerable than the commune of Karimama. This is due to the fact that Malanville has less forest cover area. Overall the Karimama municipality is more vulnerable (Figure 3(b)) due to its poverty and its weaker pre-existing physical, social, economic and environmental vulnerability conditions.

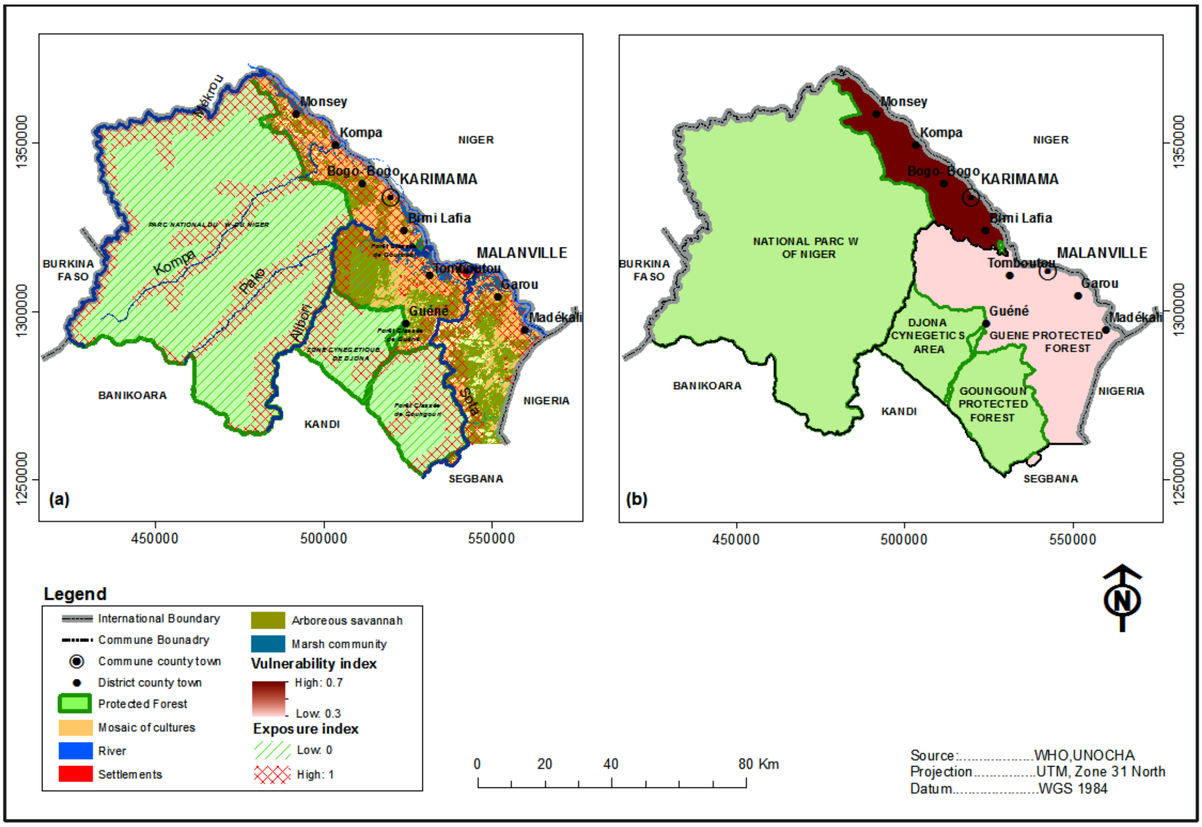

Figure 3: (a) Flood exposure, **(b)** Flood vulnerability of the Bénin Niger River Valley

In the figure 6, the risk areas are those in the red colour. Even if 90% of the districts are located in the area of hazard, they are not all at the same degree of risk due to their different degrees of vulnerability. 70% of the districts are at high risk. District at risk are: Malanville, Karimama, Kompa, Birni-Lafia, Bogo-Bogo, Madécali, and Toumboutou. These populations were estimated at about 165,721 inhabitants (INSAE, 2013).

These results corroborate findings from both previous observed flood events and relevant studies (Benin, 2010, 2012, 2013). Though, our results provide a good contribution to the understanding of flood risk in the Benin Niger River Valley, some limitations have been identified. Using one kilometer resolution for the spatial distribution of the intensity level of flood hazard “may mask some micro-variations such as crucial elevation changes in the topography that have a direct impact on the occurrence or intensity of the flood hazard” (El Morjani et al., 2007, p.24). It should be kept in mind that vulnerability is dynamic and site-specific. Development programs that enhances community resilience to flood hazards may reduce their vulnerability over time. Furthermore physical, social, economic and environmental indicators are not constant and our research is unable to capture future changes in the indicators. Therefore, the findings of this paper run the risk of being limited in time scale. Despite these limitations, our study is the first to deal with such an assessment in the area and provides an adequate depiction of the overall spatial extent of flood hazard and the vulnerability profile of municipalities in the Benin Niger River Valley. In addition to contributing to research knowledge, the results can be used to identify areas to focus on in case of emergency and for risk reduction programs. However, further research is needed to have more accurate and high resolution data to improve the hazard assessment and to develop vulnerability indicators at the district or household level.

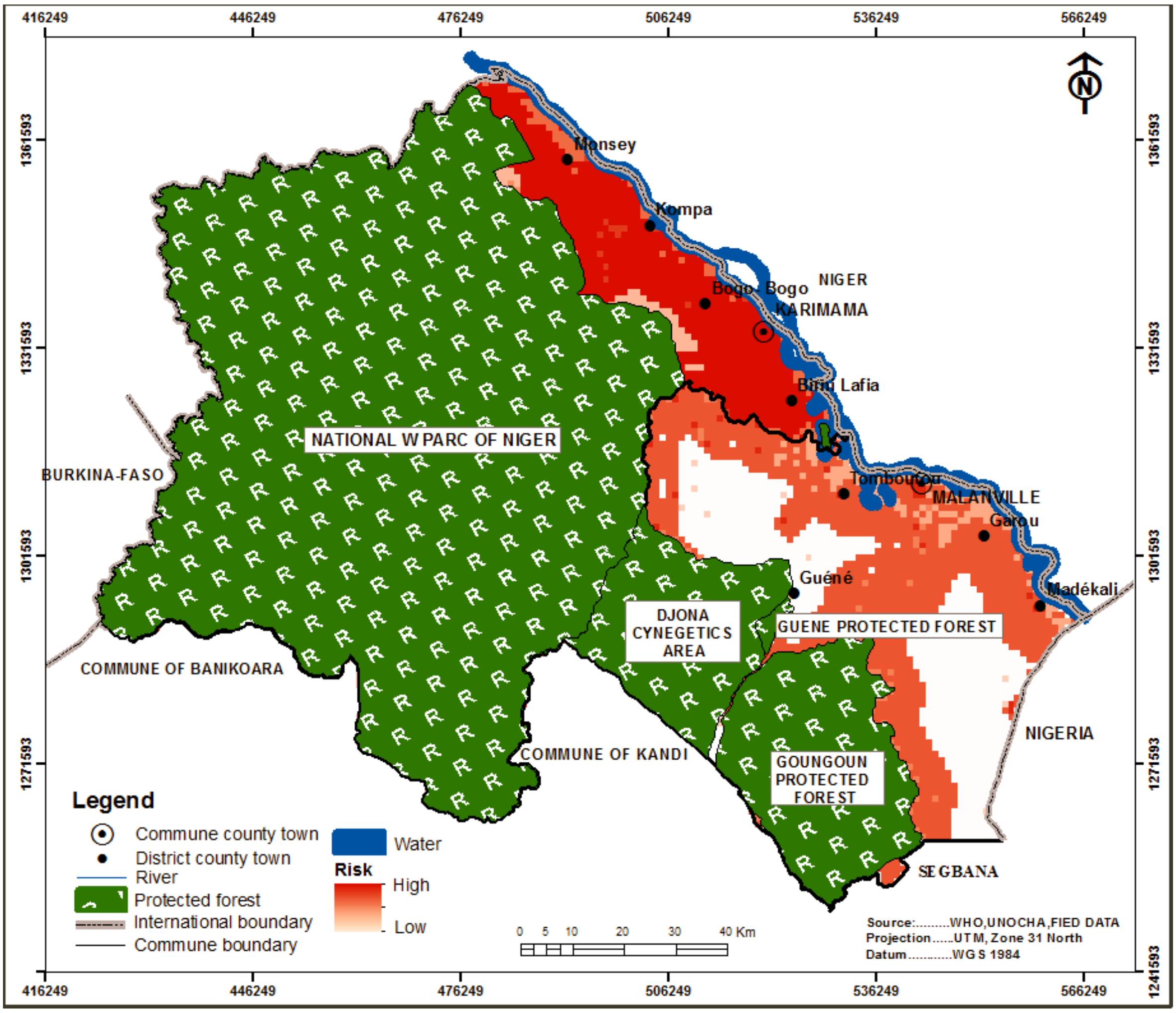

Figure 6: Flood risk map of the Bénin Niger River Valley

5. Conclusion

This study, aimed at assessing flood vulnerability and risk in the Bénin Niger River Valley came to the conclusion that since almost all of the area's populations settled in flood prone areas, they are likely to be exposed to flood hazard,. The hazard assessment shows that the low-lying areas that border Niger's bed streams and their tributaries are highly affected by the hazardous flood events. Except for some parts of the district of "Guéné", most of the people living in this segment of Niger River are highly vulnerable to flood hazard. The assessment reveals that the municipality of the Karimama is more vulnerable than the municipality of Malanville.

Disclaimer

The designations, presentation, findings, interpretations and conclusions expressed in this article are entirely those of the authors and should not be attributed in any manner to the World Health Organization, or the United Nations Office for the Coordination of Humanitarian Affairs.

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