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Analysis of Vulnerability to Drought and Flooding in the Ouémé River Basin at Bétérou in Benin (West Africa)

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Abstract

In Benin, the principal risks which threaten the populations are the floods and the drought. The objective of this work is to analyze the zones vulnerable to the flood and the dryness in the catchment area of Ouémé with Bétérou. To achieve this goal, of the data climatological (height of rains day laborers and monthly) of 1965 to 2012 were collected. The vectorial data of occupation of the grounds of the zone of study are extracted from the data base of Ifn-2006 and are brought up to date starting from the images satellite. The analysis of the results shows that the zones of weak vulnerability to the flood cover 80 % of the sector of study and are met a little everywhere on the basin. The zones of moderate vulnerability to the flood occupy 15 % of the territory. The zones of strong vulnerability to the flood occupy 5 % of the territory. For the floods the zones at the weak risk cover 8 % of the territory of study, the zones at the average risk cover 87 % of the territory. The zones at the strong risk occupy 5 % of the territory and extend mainly in the Western part, in the zone of Djougou. As regards the drought, it is necessary to retain that 12, 55 % of the surface of the basin are slightly vulnerable to the drought, 49, 35 % of the basin are fairly vulnerable. The zones with strong and very strong vulnerability respectively occupy 12, 71 % and 24, 80 % of the surface of the basin.

Introduction

The climates of West Africa and Benin are subject to wide variations and the consequences are detrimental to sustainable development (Ogouwalé, 2001). This climate crisis can be attributed to the absence, rarity, excess or poor spatial-temporal distribution of rainfall (Boko *et al*., 2004; Vissin, 2007); Or social choices that relegate risk prevention to a low priority (Dionne, 2006). Also, because of their immediate and lasting impact on the natural environment, issues of climate change and variability are now a concern of scientists around the world.

Benin is not immune to these extreme events, which often lead to heavy losses in terms of loss of life, destruction of property and environmental degradation (CPP, 2008). As in the case of some countries of the world (USA: violent deadly tornadoes in 2010, Russia: heat wave of 2010 having caused some 56,000 deaths, floods in Pakistan and China, earthquakes in China, Chile, In Haiti on 12/01/2010 with 200,000 deaths, France: storm Xynthia from 27 to 28/02/2010, etc.) (ADB, 2012), Benin experienced, for example, a particularly disastrous year in 2010.

Indeed, in the period from September 1 to November 24, 2010, the entire Beninese territory was hit by regular and heavy rains, which led to catastrophic floods with very heavy damage: 55 communes out of 77 in Benin Been affected and to varying degrees; Approximately 680,000 people were affected, of which 150,000 lost their homes and 46 died; 11,985 tons of agricultural products and 133,047 hectares of crops were destroyed and 81,000 head of cattle were decimated; 55,000 homes, 278 schools, ie 600 classrooms and 92 health centers have been completely or partially affected (WHO, Benin, 2011).

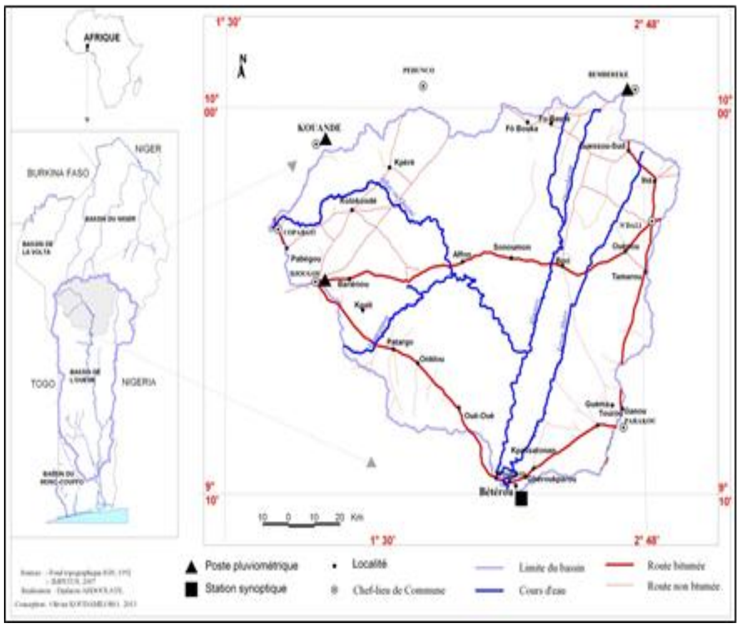
But it must be noted that since the 1970s Benin has also experienced a prolonged drought which has been mainly translated into climate by a decrease in annual rainfall with a lag in latitude of the inter-annual isohyets and a decrease in the number of Days of rain (Lawin, 2007). This phase of drought due to climatic damage has been accompanied by an edaphic peony linked to the degradation of Benin's natural environment (land degradation, loss of biodiversity), accelerated by anthropogenic pressures on natural resources Cultivation, inappropriate cultivation techniques, shorter and shorter fallow periods, etc.) (Le Lay, 2006).

In the different regions of Benin, vulnerability is manifested by deterioration in crop yields and losses (Issa, 1995). This situation is due to the lack of rainfall (Afouda, 1990), to the reduction of the duration of the agricultural seasons (Issa, 1995), to thermal warming and to the rainfall increase (Ogouwalé, 2006) Climates.

It is therefore expected that in the coming years alternating situations of drought and excess rainfall will occur (Issa, 1995).

The consequence of this situation would be the increase in hydro-climatic disasters (Lequien, 2002). It therefore seems necessary to analyze areas vulnerable to flooding and drought in the Ouémé watershed in Bétérou. This basin is located in northern Benin and has geographical coordinates: latitudes 9 ° 30 'and 10 ° 00' to the north, and longitudes 1 ° 30 'and 2 ° 48'.

Figure 1 Geographical Situation of the Ouémé Basin in Bétérou



Data and Methods

Data

Several types of data were needed to carry out this research. Climate data (daily and monthly rainfall) for the period 1965 to 2012 are obtained at ASECNA.

Land-use vector data from the study area are extracted from the IFN-2006 database and updated from satellite imagery (Landsat 8_OLI-TIRS, 2013, 30 m resolution; GeoEye images II, 2010-2012 of 0.5 m resolution). From the topographic map of the Upper Ouémé basin in Benin to 1/250000 of the IGN were used to extract the hydrographic network.

Geological maps at 1 / 200,000 of the catchment area, provided by ORSTOM, allowed appreciating the geology of the terrain. The processing of a Digital Model of Terrain (DTM) extracted from the SRTM 90 m to be used to extract the details on the morphology of the terrain. Soil conditions were defined from the IMPETUS-Benin vector data. Given the multisource nature of the data, several types of processing were required.

The digitization of the hydrographic network was carried out using the ArcGIS 10.1 software as well as the extraction of the information contained in the topographic, soil and geological maps. The various data collected are integrated into the ArcGIS 10.1 GIS software to put them in a readily usable format.

These data are used to determine the areas most affected by environmental degradation due to the occurrence of hydro-climatic phenomena.

Methods

Assessment of the Risk of Flooding In the Ouémé Watershed at the Outlet of Bétérou

For flood risk assessment, the variables defined are: drainage density, geology, structural domain, underground drainage, slope, permeability induced by the fracture network, type of occupancy Of the soil, and the rainfall intensity. The risk of river flooding is the result of a combination of vulnerability to flooding and flood hazard (Saley *et al*., 2003).

Flood Hazard Analysis

Identification of the hazard is the first essential phase in the development of risk mapping. Two parameters are used to map the hazard. From the precipitation data (1965 - 2012), the isohyet map is established. Three classes of rainfall are defined: weak, strong and very strong.

The second parameter is soil cover, which retains a variable proportion of rain during a precipitation. Taking into account the role of different land-use classes (Saley *et al*., 2005) in the production of surface flows, a classification is made and allowed to retain three classes: weak role (dense semi-deciduous forest And planting), strong role (fields and fallow land), very strong (agglomerations, marshes and water bodies). The intersection of these two factors (rainfall and soil cover) made it possible to map the spatial extent and the zones potentially exposed to climatic vagaries that could cause flooding in the basin**.**

Flood Vulnerability Analysis

The variables necessary to determine this vulnerability are of several types, because it is the combined action of several factors that causes flooding (Dia *et al*., 2006). These include drainage density, geology, structural domain, underground drainage, slope and permeability induced by soil type, etc. Only data on the hydrographic network, drainage density, geology, slope and soil are considered in this work due to the lack of up-to-date and formalized data for the other parameters. The drainage density map has been combined with the geological map, the slope map and the soil map to give the vulnerability map to the flood.

Flood Risk Mapping

To obtain the map of the risk of flooding by overflow, the combination by codification of the vulnerability maps and the hazard was made. The risk of flooding is defined as the crossing of the previously defined hazard and the vulnerability. A strong flood hazard in a weakly vulnerable area is highly risky. Thus, these cards previously coded have made it possible to obtain the different levels of risks that are, strong, medium and low.

Analysis of the Risk of Drought

In this study, emphasis is placed on the analysis conducted on drought monitoring indicators.

On the basis of the rainfall indices, a calculation of the occurrences of drought is carried out to produce the map of occurrences of deficit years in rainfall (only in the extremely dry years).

Analysis of Properties Exposed To Drought

The losses caused by drought affect ecological aspects (degradation of vegetation cover and soil, drying up of wells, etc.) and socio-economic aspects (poverty, food insecurity, conflicts, etc.). But this study is limited to the impacts of drought on land use, especially on agriculture, natural vegetation.

Drought Vulnerability Assessment

This step consists of assigning values for the sensitivity and adaptability parameters of the elements exposed to the risks. Vulnerability is the sum of these values, which largely takes into account the field reality (Table I).

Table 1 Weighting Table for Vulnerability to Drought of Exposed Goods

Well exposed	**Classification**	**Sensitivity (Low: 1 Student: 3)**	**Adaptability (High: 1 Low: 3)**	**Vulnerability (1-6)**	**Vulnerability class (Low, medium, high)**	**Rank**
Forest	Light forest					
	Dense forest					
	Gallery forest					
Savannah	Wooded Savannah					
	Shrub savannah					
	Wooded Savannah					
Production System	Flooded agriculture					
	Rainfed agriculture					

The combination of these two factors (values of the parameters sensitivity and adaptability of the elements, as well as the occurrence of droughts) in the GIS allows the development of the map of vulnerability to drought.

Results and Discussion

Evaluation of Flood Risk in the Ouémé Watershed in Bétérou

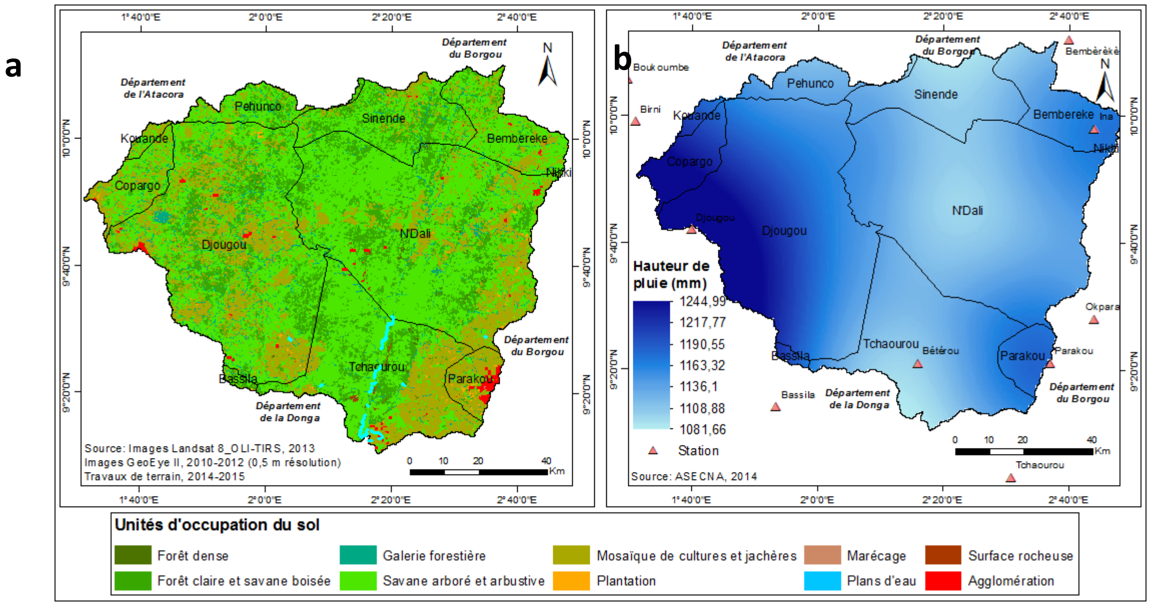
The risk of flooding from watercourses is therefore a result of the combination of hazard and flooding and vulnerability to flooding (Saley *et al*., 2003).

Evaluation of the Flood Hazard of the Ouémé Watershed in Bétérou

A comprehensive and reliable analysis of the flood risk cannot therefore avoid one of these two elements, namely hazard and vulnerability, and must integrate precisely all of their characteristics (Peduzzi, 2006) . The flood hazard map thus represents areas where there is a risk of flooding, even where no flooding is historically known.

Thus, in order to map the flood hazard, the ground cover map (Figure 2A) and the rainfall field map (Figure 2B) were previously established. The combination within a GIS of these two thematic maps enabled to obtain the map of the flood hazard.

Figure 2 Distribution of Soil Cover (2A) and Rainfall Intensity (2B)

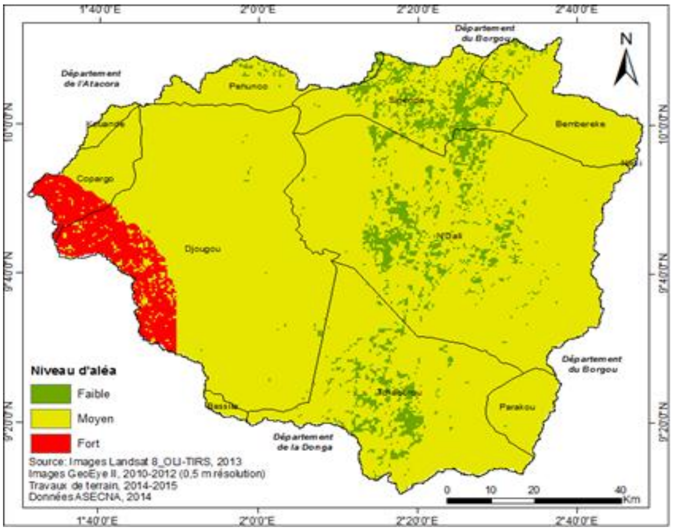


The analysis of Figure 2 reveals that the hazard refers to hydro-climatic phenomena and their consequences on the flow of water. It is the rainfall that triggers the floods (Figure 2B). Indeed, the occurrence and intensity of rainfall, natural parameters that cannot be controlled, whatever the preventive measures, are the predominant parameters of the flood.

Figure 2B shows that the Djougou station is the most watered (1244 mm). A moderate field is observed in the center (between 1080 and 1100 mm). Figure 2A shows that the Ouémé watershed is dominated by mosaics of fields and fallows that are distributed throughout the catchment. The formations of the natural vegetation cover are thin forests galleries, clear forests and wooded savannas, pockets of semi-deciduous dense forest and savanna trees and shrubs.

It must therefore be remembered that it was the crossing or superimposition of these two factors (rainfall and vegetation cover) that made it possible to map the spatial extent and zones potentially exposed to the vagaries of the climate that could cause flooding in the catchment area of l 'Ouémé in Bétérou (Figure 3).

Figure 3 Presentation of the Flood Hazard in the Ouémé Watershed in Bétérou



From the analysis of Figure 3, it should be noted that the flood hazard in the Ouémé watershed at Béterou is divided into three classes (low, medium, high).

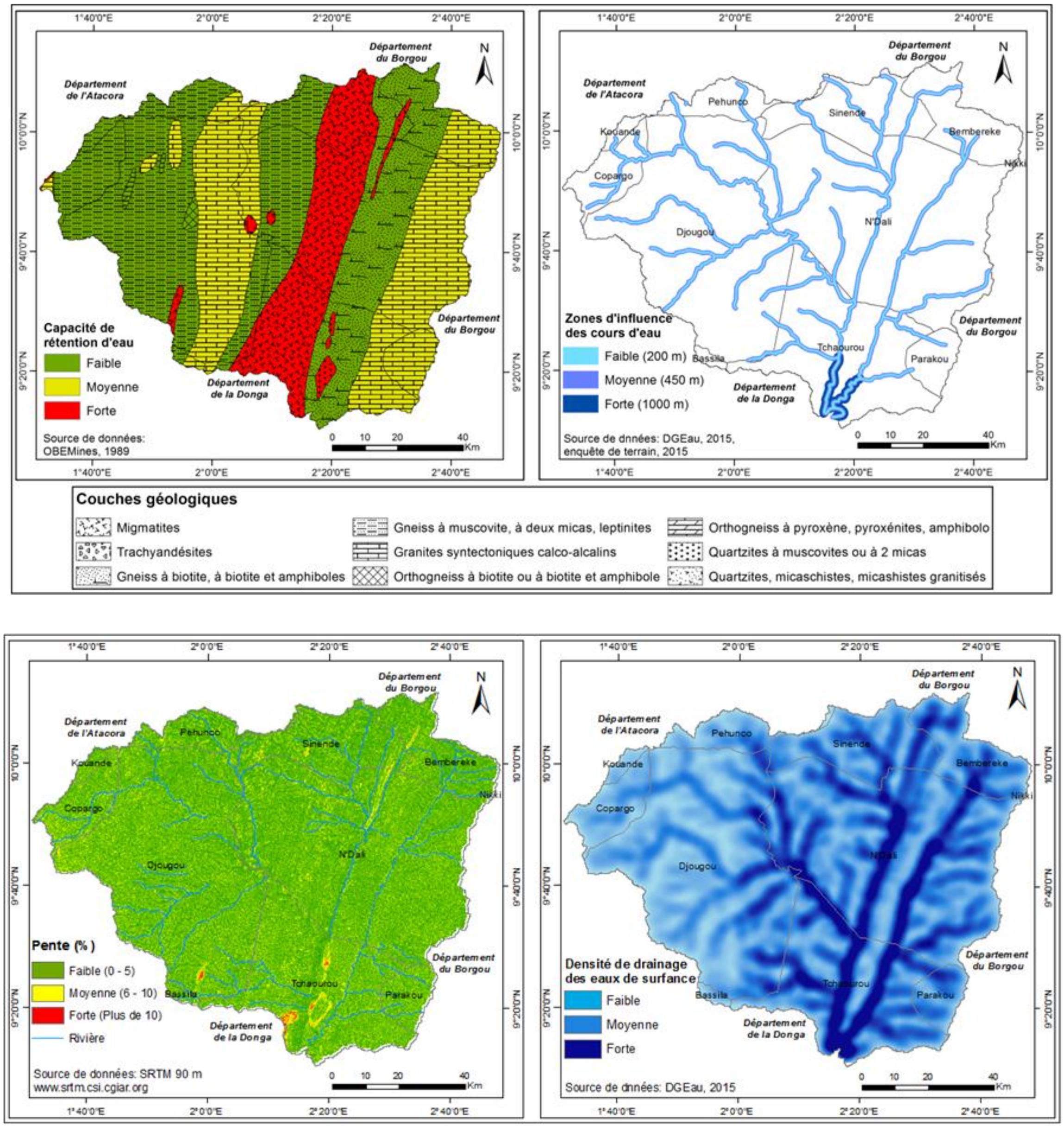
It appears that the zone with low hazard occupies 7.31% or 736.54 km2 of the surface of the watershed. These low-hazard zones are scattered throughout the territory and correspond to areas with medium dense vegetation cover (forest-crop mosaic, savanna). . Medium hazard zones occupy a large part of the entire catchment area. They represent 87.75% or 8841.91 km2 of the watershed area. The high hazard occupies 4.94%, ie 497.37 km2 of the catchment area and corresponds to the areas with a high rainfall intensity. When the soil is not covered with rather dense vegetation, with an annual rainfall of more than 1200 mm, the risk is maximum. The localities of Djougou, Copargo, and Bassila are located in this area.

These results constitute guidelines for all hydro-agricultural development work. But it can not be better appreciated without the proper study of vulnerable regions.

Sectors Vulnerable To the Flooding Of the Ouémé Watershed in Bétérou

The vulnerability map to flooding comes from the combination of various maps within a GIS. Flood vulnerability identifies all areas where the intrinsic characteristics of the environment (geological and geomorphological characteristics) are likely to promote flooding. The different parameters used to produce the map of the areas vulnerable to flooding are presented in Figure 4.

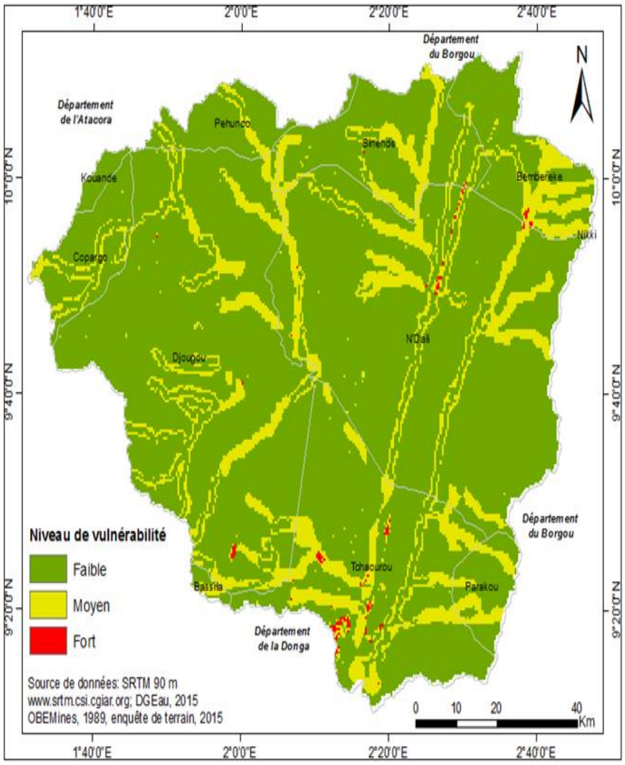
Figure 4 Different Thematic Maps for the Establishment of the Vulnerability Map to the Flood: A) Map of the Litho-Structural Domains; B) Map of the Zones of Influence of the Rivers; C) Slope Map; D) Drainage Density Map



This figure 4 presents the geomorphological characteristics (slope of the ground, drainage network) and geological (litho-structural domains) of the Ouémé basin in Bétérou. These are the various factors taken into account in the flood vulnerability mapping.

The cross-analysis of these factors in the GIS enabled the development of the flood vulnerability map in the Ouémé watershed in Bétérou (Figure 5).

Figure 5 Vulnerability to the Flooding of the Ouémé Watershed in Bétérou



Flood vulnerability identifies all areas of the environment that are likely to promote flooding. The flood vulnerability map shows three areas whose vulnerability to flooding varies from weak to strong.

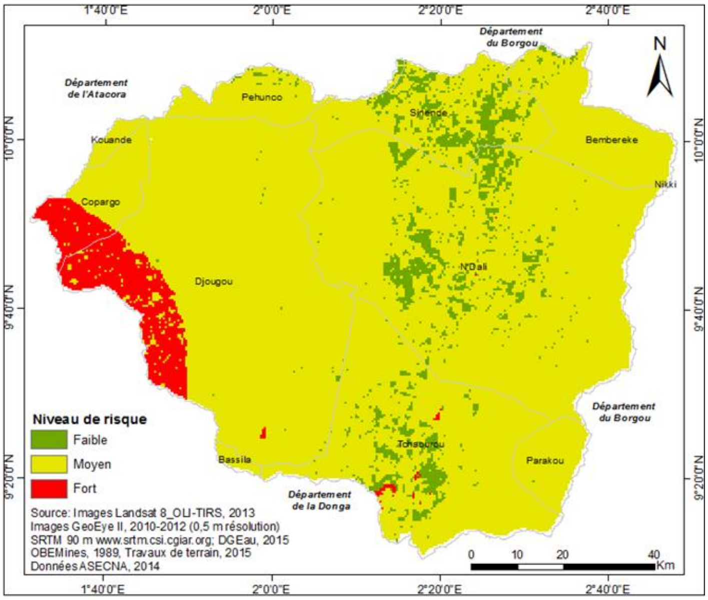
Areas with low vulnerability to flooding cover 80% of the study area and are encountered throughout the basin.

Areas of moderate vulnerability to flooding correspond to areas of medium slope where runoff on slopes on the slopes of the Atacora Mountains in the north and Aledjo in the west does not allow water to stagnate. They are also located on the edge of the minor bed and at the lowest points of the major bed of the Ouémé river and these tributaries, the important ones being the Affon Ouémé rivers (up to its confluence with Alpouro), Donga, Wèwè And the Térou. These areas occupy 15% of the territory. Areas of high vulnerability to flooding occupy 5% of the territory. These areas are scattered over the basin in areas with steep slopes.

Sectors at Risk of Flooding in the Ouémé Watershed in Bétérou

The cross-analysis of factors related to the vulnerability of the terrain to flooding and hydro-climatic factors within a GIS enabled the mapping of areas at risk of flooding. Thus, Figure 6 presents the areas at risk of flooding evaluated by the crossing of the thematic maps relating to the vulnerability to the flood and the hazard (trigger factor).

Figure 6 Map of Zones at Risk of Flooding in the Watershed of Ouémé in Bétérou



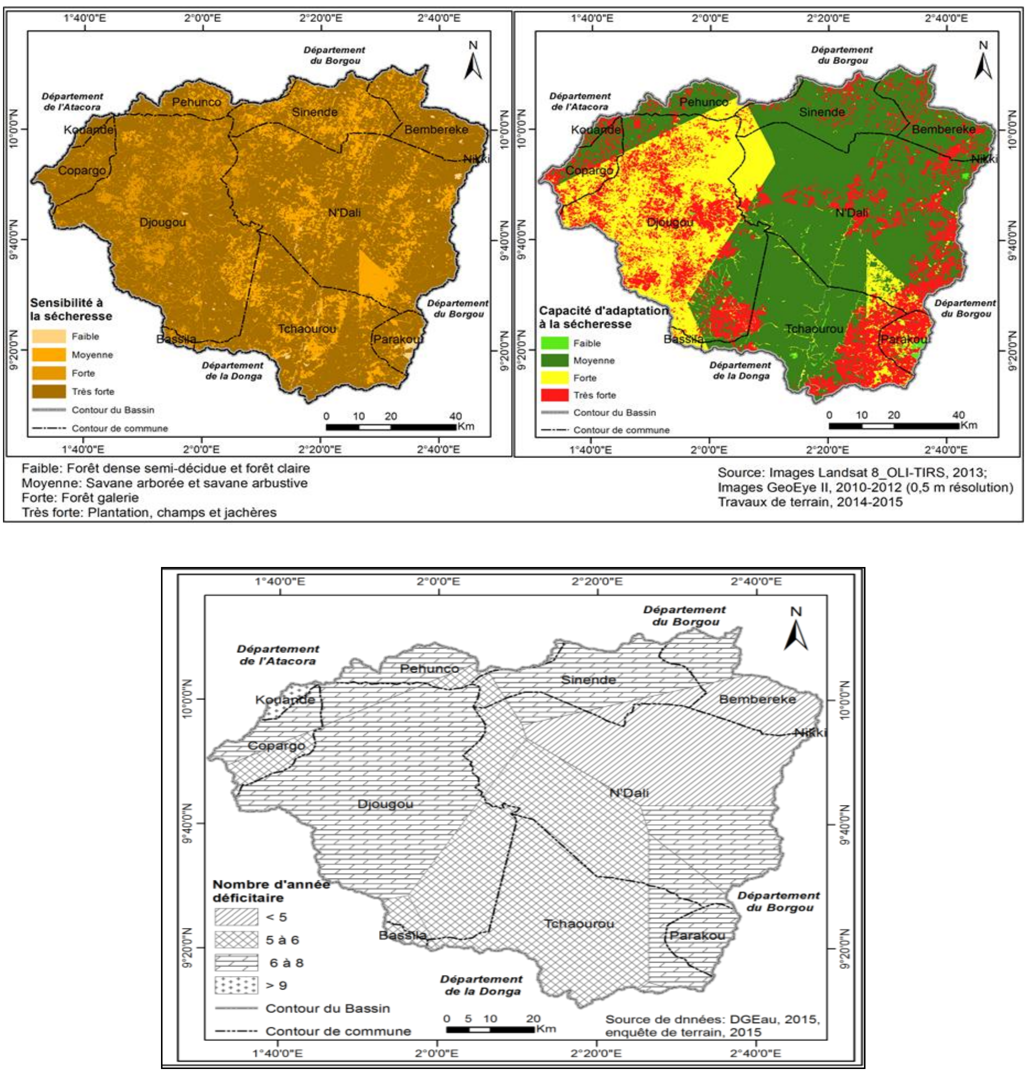
The analysis in Figure 6 shows areas of low, medium and high risk of flooding in the Ouémé basin at Bétérou. The low risk areas cover 8% of the study area, the medium risk zones cover 87% of the territory. High-risk areas are located in medium to low-slope areas with more or less dense cover, occupying 5% of the territory and mainly in the western part of the Djougou area. These areas present a clear danger during floods. Since the risk of flooding is previously defined as the crossing of the hazard and the vulnerability, it is necessary to retain that a high flood hazard in a weakly vulnerable zone is highly risky.

In sum, the flood risk map establishes the extent and extent of flooding and provides a solid basis for information campaigns to populations, informs the regional authorities responsible for possible developments and Areas.

Evaluation of Drought-Affected Areas in the Ouémé Watershed in Bétérou

To date, there is no credible model of global drought risk. Indeed, studies show that the impacts of drought can only be partly attributed to a deficit rainfall. Figure 7 shows the different maps used to determine vulnerability to drought in the Ouémé watershed in Bétérou.

Figure 7 Different Thematic Maps for the Map of Vulnerability to Drought A) Sensitivity to Drought B) Adaptability to Drought C) Map of the Occurrence of Years Extremely Deficient

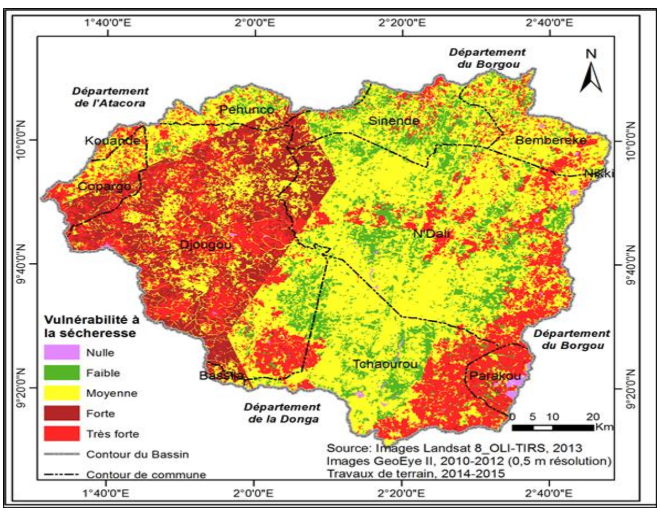


From the analysis of Figure 7a, which concerns sensitivity to drought, four classes of sensitivity are defined: weak, medium, strong and very strong. For the adaptability the same classes were obtained. The properties exposed are differentiated into several classes to facilitate the estimation of their vulnerability. Thus, a sensitivity value and an adaptive capacity value are assigned to each class.

On the basis of the pluviometric index maps, a computation of the occurrences of drought was carried out for the realization of the map of occurrences of rainfall deficit years. The indices used correspond to those of the extremely dry years according to the classification of McKee *et al*. (1993), that is, years with values of standardized precipitation indices less than or equal to -2 (Figure 7c).

The sum of the values of sensitivity and adaptability corresponds to the rank of the vulnerability of the exposed good. This work was done in close consultation with the local populations to take account of the reality on the ground. The resulting vulnerability map clearly shows areas vulnerable to drought depending on the degree of sensitivity (Figure 8).

Figure 8 Map of Vulnerability to Drought at the Scale of the Ouémé Watershed in Bétérou



From the analysis of Figure 8, it should be noted that vulnerability to drought is a combination of several factors. It should be noted that in terms of land use, the Ouémé watershed is dominated by the mosaics of fields and fallows that are distributed throughout the catchment. The formations of the natural vegetation cover are thin forests galleries, clear forests and wooded savannas, pockets of semi-deciduous dense forest and savanna trees and shrubs. Thus, taking into account these different aspects, it should be noted that 12.55% of the area of the basin is weakly vulnerable to drought, 49.35% of the basin are moderately vulnerable.

The areas with high and very high vulnerability occupy respectively 12.71% and 24.80% of the area of the basin.

It should also be pointed out that the agricultural populations are the poorest in the basin and therefore very vulnerable to hydro-climatic extremes, such as droughts, which create profound water deficits for crops.

Discussion

The station of Djougou is the most watered (1225 mm) of the Ouémé basin in Bétérou. Thus, the distribution of annual average totals does not respect a clear geographical order. In reality, to the northwest is a mountain range (Atacora) and the basin seems to undergo the orographic effect. These results confirm the results obtained by Yabi in 2008. Moreover, the influence of local geographical factors (topography and vegetation cover) also seems to explain this state of affairs (Afouda, quoted by Yabi, 2008). Indeed, the rainfall (wet) field is stationary throughout the city (Akognongbé, 2014).

The study also found that the low-hazard area occupies 7.31%, ie 736.54 km2 of the catchment area. Medium hazard zones occupy a large part of the entire catchment area. They represent 87.75% or 8841.91 km2 of the watershed area. The high hazard occupies 4.94%, ie 497.37 km2 of the catchment area and corresponds to the areas with a high rainfall intensity. A similar study was carried out by Kodja (2013), which showed that in the Ouémé valley at Bonou, 11.38% or 1024 m represent the sectors exposed to the vagaries of low climatic conditions while 47.45% or 4270 m2 are Exposed to high risks and 41.17% or 3706 m2 with very high risks.

This study also showed that zones of moderate vulnerability to flooding correspond to areas with medium slope, which is confirmed by the results of Koumassi in 2014.

Unlike the work done by Kodja (2013) and Koumassi (2014), this study has the advantage of including in addition to vulnerability to flooding, vulnerability to drought. This gives it a more complete character in the hydro-climatic risk analysis in the study area.

Conclusion

At the end of this study, it should be pointed out that in the Ouémé catchment area in Bétérou, high vortices are obtained in areas with high concentrations of agglomerations, presence of water bodies, swamp and road, High rainfall intensity. Mean hazards in areas of low concentration of localities with presence of water bodies, swamp and road with average rainfall intensity. On the other hand, the zones characterized by a virtual absence of localities, and zones of natural vegetation have low level hazards. So it would be good to see in future studies to reduce the direct or indirect adverse effects of hazards on the agri-food system and populations

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