International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 38 No. 4 Feb. 2023, pp. 906-924
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http://www.ijias.issr-journals.org/

Contribution of multicriteria analysis and GIS in the discrimination of flood risk areas on the Allada plateau in Southern Benin

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ABSTRACT: Flood vulnerability mapping and assessment is an important component of flood prevention and mitigation strategies, as it allows the identification of the most vulnerable areas based on the physical characteristics that determine flood propensity. This study aims to identify and map the factors related to flood risk in the Allada Plateau using a multi-criteria approach, in particular the Saaty Hierarchical Analysis Process (HAP) technique and Geographic Information Systems (GIS). The methodology used in this study allowed the identification of six (06) criteria considered relevant and conditioning the floods, namely: drainage density, slopes, rainfall intensity, soil type, land use and population density. All these criteria were defined as raster datasets with a resolution. The AHP technique was used to calculate the weights of the criteria and factors. The relative importance of the selected criteria made rainfall intensity the most important criterion with a weight of 56%, followed by slope with 26%, and finally drainage density with a weight of 12%. The hazard map generated from this combination shows that 25% of the Allada plateau is a high-risk area. As for the vulnerability map, the most important criterion is population density with a weight of 88% followed by land use with 12%. The combination of the two maps in a GIS shows that the areas vulnerable to flooding occupy 35.37% of the study area. The flood risk map obtained from the combination of the hazard and vulnerability map shows that flood risk areas cover 28.68% of the area of the Allada plateau.

KEYWORDS: Hazard; flood; risk; vulnerability; multi-criteria decision analysis.

1 INTRODUCTION

In recent decades, several countries in the world have been severely affected by extreme weather events such as droughts, extreme rainfall [1] the most recent being the floods in Pakistan with more than 1400 deaths including 550 children [2]. The multiplication of these extreme events can be considered as indicators of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) considers that these changes, different from natural climate variability, are related to the increase in the concentration of greenhouse gases (GHG) in the atmosphere [3]. The global warming that the world is currently experiencing is the cause of the increase in extreme phenomena responsible for hydro-climatic risks, including floods. These risks are a major concern for land use planning and management [4]. In the future, they should multiply and increase in intensity with consequences that could prove catastrophic for human societies [3]. Among these risks, floods represent a danger to property and people in most regions of the world. In the broadest sense, floods include several types of phenomena. These extreme weather events are disastrous for urban communities that lack sustainable solutions for dealing with them [5]. The costs of these natural disasters have doubled in the last ten years [6].

In Africa, the problem is likely to worsen as the Intergovernmental Panel on Climate Change (IPCC) has predicted an increase in the frequency and intensity of floods and droughts [3] on the continent due to climate change. Unexpected floods and high-water levels cause many casualties and property damage [7]. In West Africa, floods are one of the most devastating natural disasters of climate change impacts ([8], [9]).

In Benin, flooding is increasing due to the frequency of exceptional rainfall and anarchic land use [10]; [11]; [12]. Considered as one of the countries most vulnerable to the harmful effects of climate change, Benin must be able to strengthen its capacity to assess damage, plan and coordinate responses to flood risks. Towards the end of August 2010, due to heavy rainfall, Benin was again affected by severe flooding. 42 municipalities out of the 77 in Benin were flooded with significant damage: 43 deaths, 97815 homeless, 55575 houses and 276 schools flooded [10]; [11]; [12], [13]. The total damage caused by the floods Benin's economy amounted to nearly CFAF 78.3 billion and approximately 680,000 people were affected by this disaster and 46 lost their lives according to the Post Disaster Needs Assessment Report [14]. Flooding is the most prevalent and devastating natural hazard in Benin. This means that water ensures life, but it is also the most frequent and most damaging source of multiple problems experienced by most Benin populations, more specifically the Allada plateau. The latter is one of the regions of Benin where the population growth rate is high (5.06%) with an estimated 1,436,540 inhabitants in 2020. This region is the breadbasket of Cotonou, the country's largest city. It is increasingly affected by floods with a frequency and intensity that are constantly growing. The topography of the Allada plateau is very flat. This context exposes it to many environmental problems, the most worrying being the recurrent floods which result from the combined action of several factors including heavy rains which increase the level of the river, the stagnation of rainwater in the city because of low slopes. Other factors aggravate flooding, notably the silting of rivers, spontaneous and unconscious urbanization in areas of accumulation, the absence of an appropriate drainage network and, finally, construction on the banks of the river.

The development of the mapping of risk areas in Benin is therefore timely and is an essential prerequisite for effective and efficient implementation of disaster risk reduction and climate change adaptation projects. Indeed, flood susceptibility mapping and analysis is one of the most important elements of early warning systems or strategies for prevention and mitigation of future flood situations, as it identifies the most vulnerable areas based on the physical conditions that determine flood propensity [15]. It provides accessible and easy-to-read graphs and maps, making it easier for planners to identify areas at risk and prioritize their mitigation efforts [16]; [17]; [18]; [19]. Flood management is necessary not only because floods impose enormous damage on society, but also for optimal land use and stewardship.

However, the use of the multi-criteria assessment approach for flood risk assessment and mapping in Benin is still underdeveloped. Indeed, the occurrence of flood risk is a combination of natural and anthropogenic factors, which means that there is a need for knowledge about the spatial extent of flooding areas, the use of multisource data as drivers becomes a potential source for effective management and more reliable flood mitigation. For all these reasons, the Multi-Criteria Analysis (MCA) method is widely used [20], [21] to solve complex problems and assess flood risk. Many methods have been proposed for multi-criteria decision-making. The Hierarchical Analytical Process (HAP) is one of the most well-known and widely used Multi-Criteria Analysis (MCA) approaches [22], [23]. AHP is used to solve a large number of multi-criteria decision-making problems, with the pairwise comparison matrix calculating the weights of each criterion considered [22], [24], [25], [26]. AHP assumes a complete aggregation between several criteria and develops a linear additive model. The uniqueness of the application of AHP in different studies allows modeling situations of uncertainty without losing the subjectivity and objectivity of any evaluation measure.

In recent years several studies, have paid special attention to the use of AHP in natural hazard assessment, but more so in flood management in various studies [23], [24], [22], [35], [25], [27], [29]. It has been demonstrated from numerous scientific works that the AHP method has a capacity to assess and map flood risks with good accuracy and very satisfactory results. It is against this backdrop that the present study was initiated and aims to identify the factors (of hazard and vulnerability) of flood risk and to deduce the flood-prone areas on the plateau of Allada through an additive combination of these factors from the multicriteria analysis and the hierarchical analytical process (AHP) Saaty

2 Study Area

With an average altitude of 100 m [29], the Allada plateau is located in the Atlantic department grouping 7 municipalities. It covers an area of about 2037 km2 with a population of 22465 inhabitants in 1979 to 717,813 in 2013 [30], it has almost doubled in 30 years. The Allada Plateau lies between meridians 1°58'26" to 2°25'55" East and parallels 6°21'38" to 6°57'08" North (Figure 1). It extends from the valleys of Oueme in the east, Couffo in the west and the Lama depression in the north. It is limited to the south by the coastal plain (on which the coastal lagoon is located). The delimitation of the Allada plateau took into account its structural and tabular character. As a result, the area of some municipalities has been reduced when they are located partly on the plateau and partly on the plain. The Allada plateau makes up 63% of the Atlantic regions and approximately 2% of the national territory.

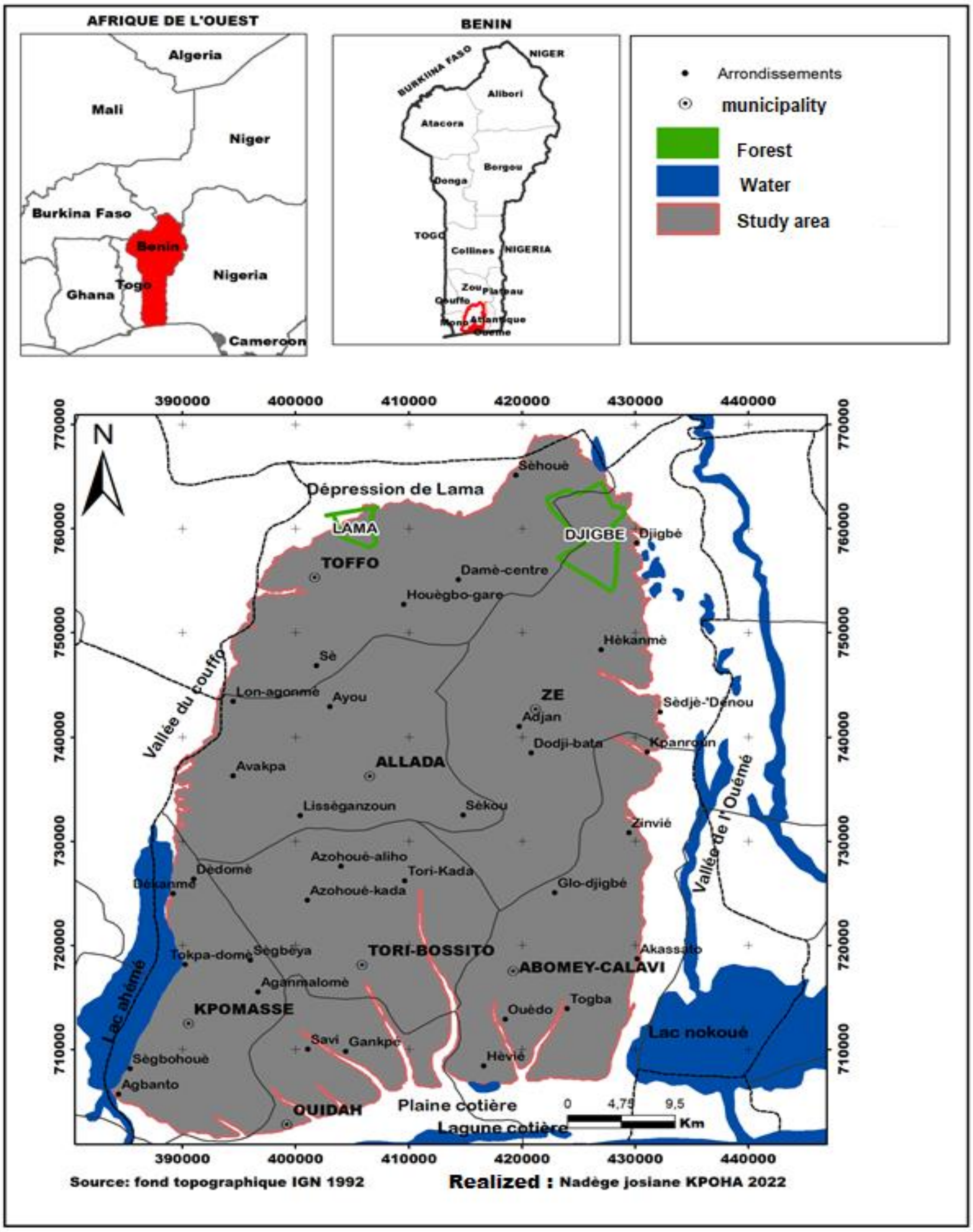

Fig. 1. Geographic location of the study area

3 RESOURCES AND METHODS

To carry out this study, several types of data were required. The analysis of these data required the use of several software programs depending on the type of processing required.

3.1 RESOURCES

The resources consist of ENVI 5.2 software for satellite image processing and ArcGis 10.5 for spatial analysis and map output.

3.2 DATA USED

The implementation of this study required the contribution of several satellite data, map backgrounds and field data. The image data are composed of two (2) Landsat 8 OLI image scenes. These scenes are: (Path 192, Row 055) and (Path 192, Row 052) each composed of nine (9) bands and satellite images of SRTM type, as well as satellite rainfall data from 2020. The total coverage of the study area required a mosaic of images. The downloaded rainfall data are Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS).

These CHIRPS data are a near global rainfall dataset of more than 35 years and cover longitudes 1.925E - 2.375E and latitudes 6.325N-6.975N. They are accessible from the link http://iridl.ldeo.columbia.edu/SOURCES/. These data were used to produce the rainfall intensity map of the Allada plateau. The cartographic backgrounds that cover the entire study area consist of topographic maps published by the National Center for Remote Sensing and Ecological Monitoring of Benin (CNATEL), all established at a scale of 1: 200,000. The demographic data of the populations of the study area and its estimates in 2020 are obtained from the National Institute of Statistics and Economic Analysis (INSAE).

3.3 Methods

3.3.1 Mapping Of Hazard And Vulnerability Factors

Within the framework of this study, the flooding factors (or criteria) deemed relevant in light of the summary from literature [31], [9], [8] and following field campaigns on the Allada Plateau are: drainage density, slopes, soil types, and rainfall intensity (as hazard factors) and land use (building density) and population density (as a vulnerability factor).

- **Land use mapping**

The land use map of the Allada Plateau is based on object-oriented classification techniques of Landsat OLI 8 satellite images of 2020 of the study area. The processing of these images was preceded by the calculation of the vegetation index (NDVI) and the building index (NDBI). An empirical segmentation was used to obtain several image objects [32]. NDVI/NDBI coupling [8] was used to classify the image.

- **Population density mapping**

Population data were mapped with discretization into the following five classes: < 200; [200; 400 [; [400; 800 [; [800; 1000 [; >1000

- **Rainfall intensity mapping**

Rainfall intensity mapping was carried out using daily satellite data. The choice of this type of data is due to the lack of complete and accessible in-situ data. Therefore, CHIRPS satellite data from the International Research Institute (IRI) online library was used. The estimation of rainfall intensity requires the calculation of two variables, the number of rainy days (NJP) and the precipitated water height (HP). The number of rainy days (NJP) was obtained from the Excel table, the NB.SI function was used to generate the rainy days according to the following condition: NB.SI (D2: D367; ">=1"), Number of value taken from the first cell to the last cell of the precipitation column, with the condition if the Value is ≥1. Indeed according to the World Meteorological Organization (WMO) a day is said to be rainy when the daily cumulative rainfall is greater than or equal to 1 mm of precipitated water. High Precipitation (HP) level is the sum of all daily rainfall, according to the function SUM (C2: C367), ie the sum of values taken from January 1 to December 31 line of the year and finally the values of rainfall intensity (IP) were obtained by making the ratio of the height of rainfall on the number of rainy days:

$$\mathrm{IP} = {}^{\mathrm{HP}}/_{\mathrm{NJP}} \qquad (1)$$

Where HP = Rainfall Height and NJP = Number of Days of Precipitation. Thus, the rainfall data after being converted to a file (csv), and exported to ArcGis 10.3 software, were saved in Shapfile format to facilitate interpolation. The ordinary Kriging method was then applied.

3.3.2 Treatment Of The Analytical Hierarchy Process (AHP) Model

Saaty's hierarchical analysis process (AHP) [33], is summarized in six steps namely:

- Decomposition of a complex unstructured problem into its constituent factors
- Development of the AHP hierarchy
- Pairwise comparison matrix determined by imposed judgments
- Assigning values to the subjective judgments and calculating the relative weights of each criterion
- Synthesize judgments to determine priority variables
- Verify the consistency of evaluations and judgments

An important part of the AHP is the calculation of the consistency ratio [33], If the consistency ratio is less than 0.1, then the mentioned matrix can be considered as an acceptable consistency. However, this AHP methodological approach can be summarized into three main levels, namely: hierarchical elaboration; pairwise comparison; and the development and prioritization matrix.

3.3.3 Hierarchical Processing

The different levels of AHP according to [33, [34], [25], [27], [28], [9], [35] are: level 0: main objective, in this case the flood risk map; level 1: criteria analysis which are the hazard map and the vulnerability map, and level 3: element considered in each criteria feature according to their influence (Figure 2 and 3). All the elements considered in each criterion were defined on the basis of previous work in Côte d'Ivoire [31], [36], ([9], [37]; [8] in Benin [38] and elsewhere in the world [39], [40], etc. and the definition of the concepts of hazard and vulnerability used in this study.

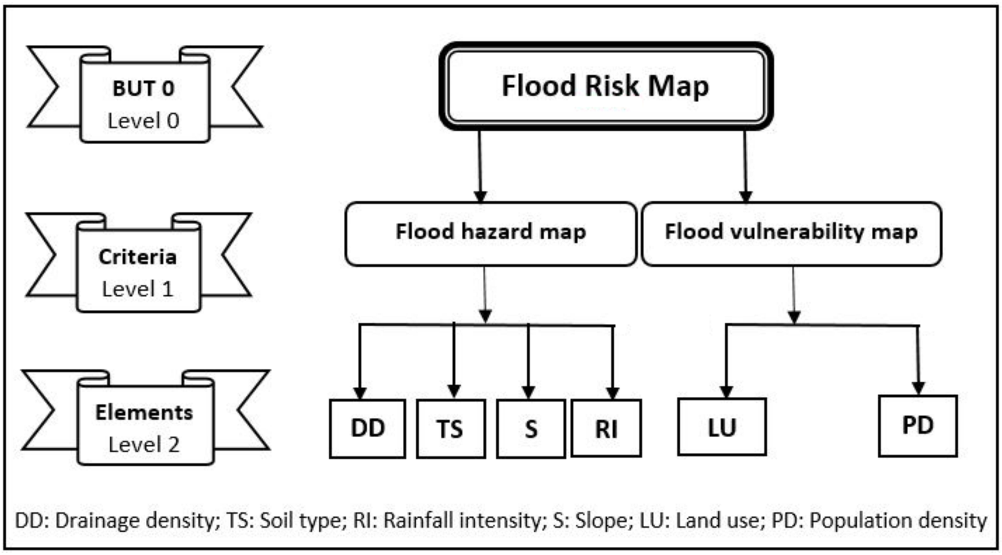

Fig. 2. Process of using the AHP model in the flood risk map

- **Pairwise comparison**

The pairwise combination is based on the scale proposed by [33], for comparison of the elements in Table 1.

Table 1. Saaty scale for various elements comparison [33]

Preference Judgement	Scale	Description
Similar importance	1	Two factors equally contribute to the objective.
Mild importance	3	Experience and judgement slightly favour one over the other.
Important	5	Experience and judgement strongly favour one over the other.
Very important	7	Experience and judgement very strongly favour one over the other.
Extremely important	9	Evidence in favour of one over the other is of the highest possible validity
Intermediary preference between adjacent scales	2, 4, 6, 8	When a compromise is necessary

The pairwise comparison is the fundamental component of the AHP process. For each pair within each criterion, the best option is assigned a score, again on a scale of 1 (as good) to 9 (absolutely better), while the other option in the pair is assigned a score equal to the reciprocal of that value. Each score indicates how well option "X" meets criterion "Y". The scores are then normalized and averaged. At least ten (10) experts provide their opinion on the relative importance of one indicator compared to another. The pairwise comparison tests were conducted by nine experts in the field of natural disasters. Their results were standardized and examined with the consistency ratio (CR) test.

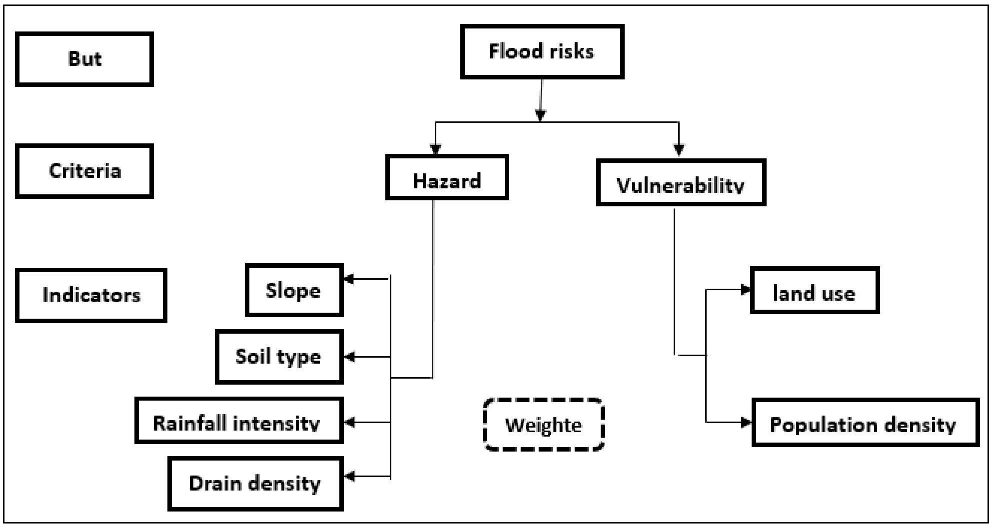

Fig. 3. Process of using the AHP model in the flood risk map

3.3.4 DEVELOPMENT AND PRIORITISATION MATRIX

The development principle is the following matrix:

- Determining the eigenvectors (Vp) of each criterion for each item is described by the following equation 2:

$$V_{P} = \sqrt[K]{W1 \times \ldots \times WK} \quad (2)$$

With k = number of parameters compared and Wk = main scores assigned to the parameters;

- Calculate the weighting coefficients (Cp), the formula is given by equation 3:

$$Cp = \frac{Vp}{Vp1 + \ldots + Vpk} \quad (3)$$

The sum of the Cp's of all parameters in a matrix must equal 1 (one).

- normalize the matrix by dividing each element by the sum of one column of the column;
- calculate the average of each row to determine the priority vector [C]
- Multiply each column by its corresponding priority vector to determine the global priority [D];
- Divide each global priority by its priority vector to determine the rational priority [E];
- Determine the maximum eigenvalue (λmax) by Equation 4:

$$\lambda_{max} = {[E]}/{K} \quad (4)$$

- Calculate the coherence index (CI) expressed by equation 5:

$$IC = {(\lambda max\text{-}k)}/{(k\text{-}1)} \quad (5)$$

- Determine the coherence ratio (CR) using Equation 6.

The consistency ratio can be interpreted as the probability that the crosstalk is completed randomly. This is because there is often some degree of inconsistency in the responses. Saaty's AHP method is flexible; it does not require that judgments be consistent or transitive, indeed, [33] defined the value of the consistency ratio. In the case where the value of the consistency ratio is less than 10%, the judgment is consistent and when it exceeds 10%, the evaluations may require some revisions.

$$CR = \frac{CI}{RI} \quad (6)$$

(RI) is the random index. The (RI) values are shown in Table II.

3.3.5 Standardization And Weighting Of Flood Hazard

Table 2. Flood hazard criteria

Criteria	Classes	Rating of the criterion	Scores	Weights
Slopes (%)	< 1	Low	9	0,27
	1 - 3	Medium	5	
	> 3	High	1	
Drainage density (Km/km^2)	< 0,60	Low	3	0,13
	0,60 - 1	Medium	5	
	1 - 1,5	High	7	
	> 1,5	Very high	9	
Soil type	Pseudogley	Very high	9	0,07
	Ferrallitic soils	Medium	5	
	Ferruginous soils	Low	3	
	Hydromorphic soils	High	7	
Rainfall Intensity (mm/J)	< 10	Low	3	0,53
	10 - 11	Medium	5	
	11 - 12	High	7	
	> 12	Very high	9	

In a nutshell, hazard refers to hydrological and climatic phenomena and their impact on water flow. Geomorphological characteristics such as slope, drainage density, soil types [40] and rainfall intensities are the different factors taken into account in the present study to map the hazard. Indeed, the hazard map has this great capacity to highlight all areas likely to be flooded. The chosen intersection parameters will help map the spatial extent and the areas potentially exposed to climatic hazards that may cause flooding. Based on the Saaty scale, different weights are assigned to each criterion to determine the hazard. The weights assigned to each criterion to determine the hazard are listed in Tables 2 and 3.

Table 3. The weights assigned to each criterion to determine the hazard

	RI	S	DD	TS	Vp	Cp
RI	1	3	4	5	2.783	0.529
S	1/3	1	3	4	1.410	0.268
DD	1/4	1/3	1	3	0.705	0.134
TS	1/5	1/4	1/3	1	0.358	0.068
Total	1,78	4,58	8,33	13	5,257	1

The relative hazard map is obtained by the following formula (equation 7):

$$\text{Hazard index} = 0.53RI + 0.27S + 0.13DD + 0.07TS \quad (7)$$

Where DD = drainage density; TS = soil type, S = slope and RI = rainfall intensity.

3.3.6 STANDARDIZATION AND WEIGHTING OF VULNERABILITY

Table 4. Vulnerability criteria for flooding issues

Criteria	Classes	Rating of the criterion	Scores	Weights
Population Density (habts/km²)	0 - 164	Very Low	1	0,8
	164 - 176	Low	3	
	176 - 229	Medium	5	
	229 - 482	High	7	
	482 - 1218	Very high	9	
Land use	Building	Medium	6	0,2
	River	Very high	9	
	gallery forest	High	7	
	Mosaic fallow	Low	3	
	Plantation	Very low	1	

In this study, flood vulnerability is made up of two criteria: population density and land use (Table 4). The weight assigned to each element in determining the extent of vulnerability is presented in Table 5.

Table 5. The weights assigned to each criterion to determine vulnerability

	PD	LU	Vp	Cp
PD	1	4	2	0,8
LU	0.25	1	0,5	0,2
Total	1,25	5	2,5	1

The flood vulnerability map is obtained from the formula in equation 8:

$$IV = 0{,}8DD + 0{,}2LU \quad (8)$$

With LU: Land use; PD: Population density. IV: Vulnerability index

- **Flood risk mapping**

A flood risk map is the result of combining two components: Hazard and Vulnerability ([41]; [42]; [43]; [8]; [35]). This model is suitable for most natural hazards and is given by this equation 9:

$$\text{Flood risk} = 0.5\ \text{hazard} * 0.5\ \text{vulnerability} \quad (9)$$

In this study, weights were assigned to the different classes and layers of thematic indicators according to their relative influence and contribution to hazard and vulnerability. The overlay technique was used for the indicators to determine the hazard and vulnerability in a first step and crossing the hazard and vulnerability to obtain the objective which is the identification and zoning of flood risk areas. All processes were performed in ArcGIS using the Algebra module in the spatial analysis tools. Then, the vulnerability layers were crossed in the GIS to finally obtain the flood risk map of the Allada plateau according to the formula.

4 RESULTS AND INTERPRETATIONS

The application of the multi-criteria analysis in the present study has resulted in the realization of numerous maps bringing a consideration aid to the decision making in the field of flooding on the Allada Plateau.

4.1 FLOOD HAZARD CRITERIA ON THE ALLADA PLATEAU

The criteria considered relevant in the mapping of hazard factors on the Allada plateau are: slope, rainfall intensity, density of natural drainage of rainwater and soil type. Indeed, the different criteria selected are of undeniable importance in the mapping of the hazard factor.

The different criteria selected such as slope, rainfall intensity, natural stormwater drainage density and soil type are of undeniable importance in the hazard factor mapping.

- **Slopes of the Allada plateau**

The interpretation of the map of the slopes of the Allada plateau (Figure 4), derived from the DEM, reveals three classes of slopes: low altitude zones (51.32%); medium altitude zones (42.53%); and high-altitude zones (4.15%).

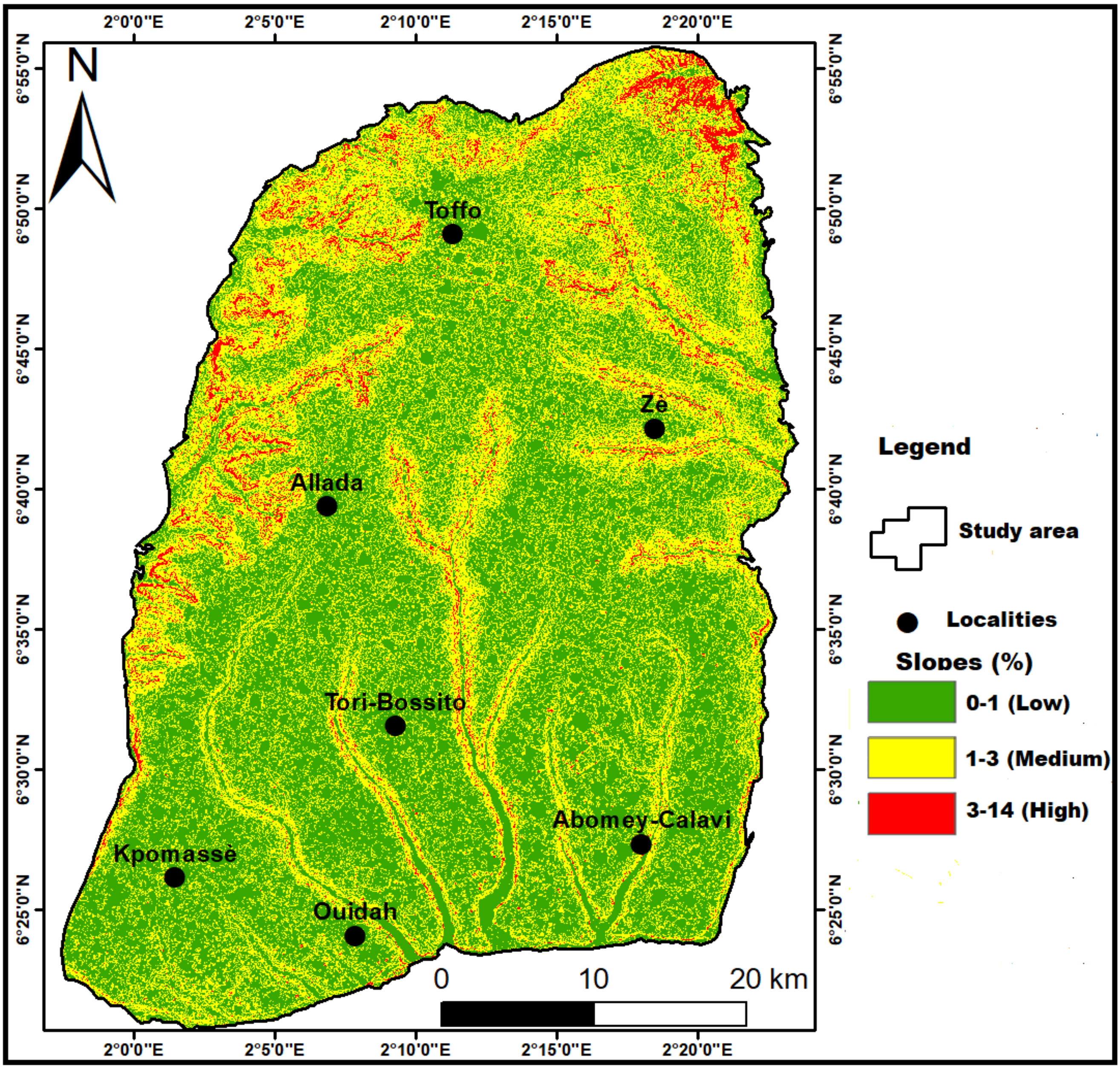

Fig. 4. Slope levels of the Plateau Allada

- **Rainfall intensity parameter on the Allada plateau**

Analysis of the rainfall intensity map of the Allada plateau (Figure 5) shows four (4) rainfall intensity classes: low intensity (7.07%), medium intensity (63.71%), high intensity (27.14%) and very high intensity (2.07%). It reveals above all how the rainfall intensities are distributed on the Allada plateau. The high rainfall intensity starts from the North to the south of the plateau, passing through the center (Toffo; Zè; Tori Bossito and Kpomassè) and the very high intensity is recorded in the south in the municipalities of Abomey Calavi and Ouidah. In sum, the overall high rainfall intensity recorded on the Allada plateau is 29.21%.

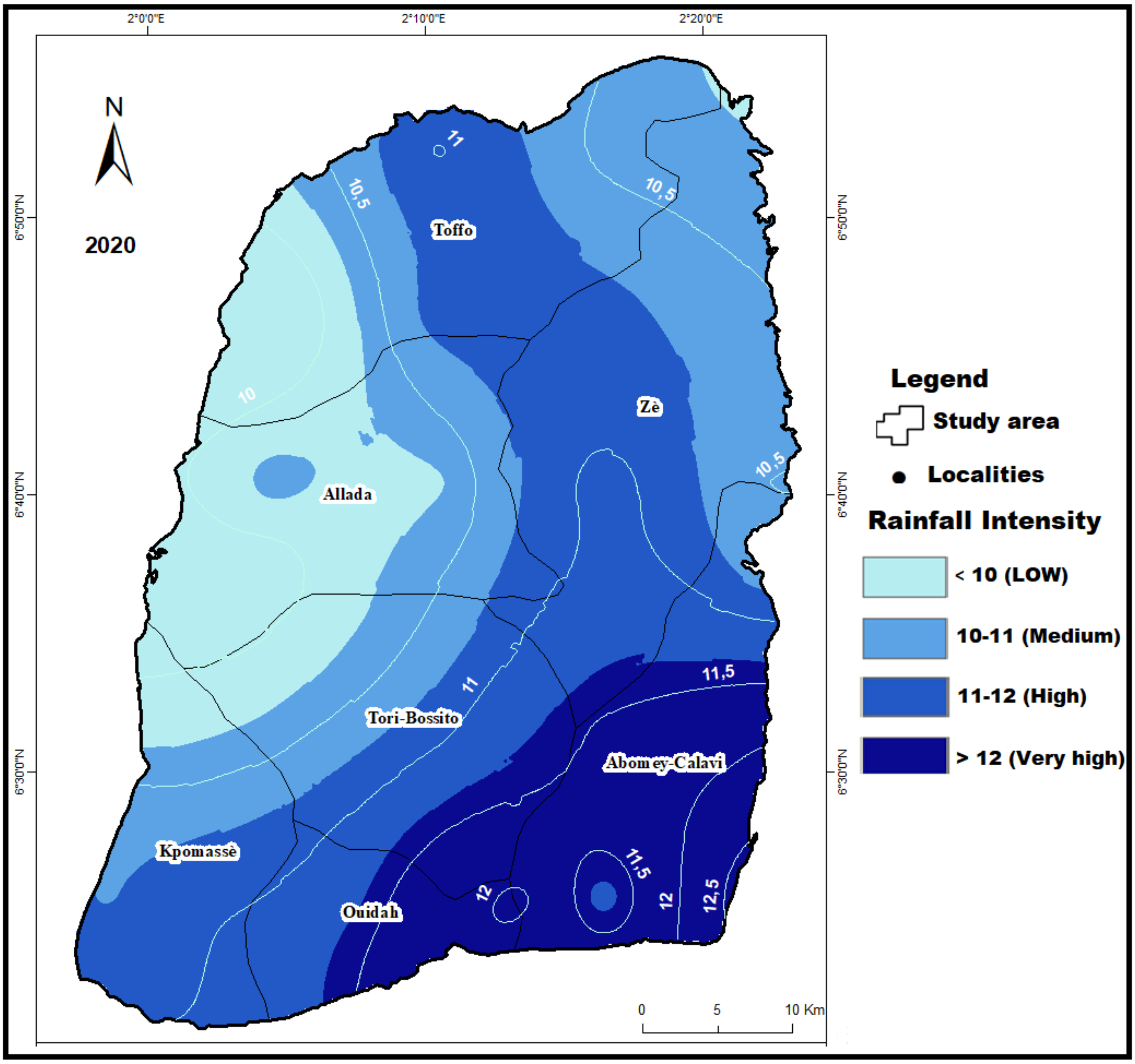

Fig. 5. Rainfall intensity on the Plateau of Allada

- **Natural stormwater drainage density parameter**

The drainage density map of the Allada Plateau (Figure 6), presents five classes from very low (15.11%) to very high (1.54%). It is spatially distributed throughout the Allada Plateau.

- **Soil type parameters on the Allada Plateau**

The Allada Plateau is made up of four types of soil (Figure 7), namely ferralitic soils (red clay soils), which occupy 91.38% of the surface area of the study area; tropical ferruginous soils occupy 0.74%; river and lake valleys represent hydromorphic soils 0.44%. And finally the pseudogley soil 7.44%. In sum, the ferralitic soil is the dominant soilin the study area. This soil has a good retention capacity.

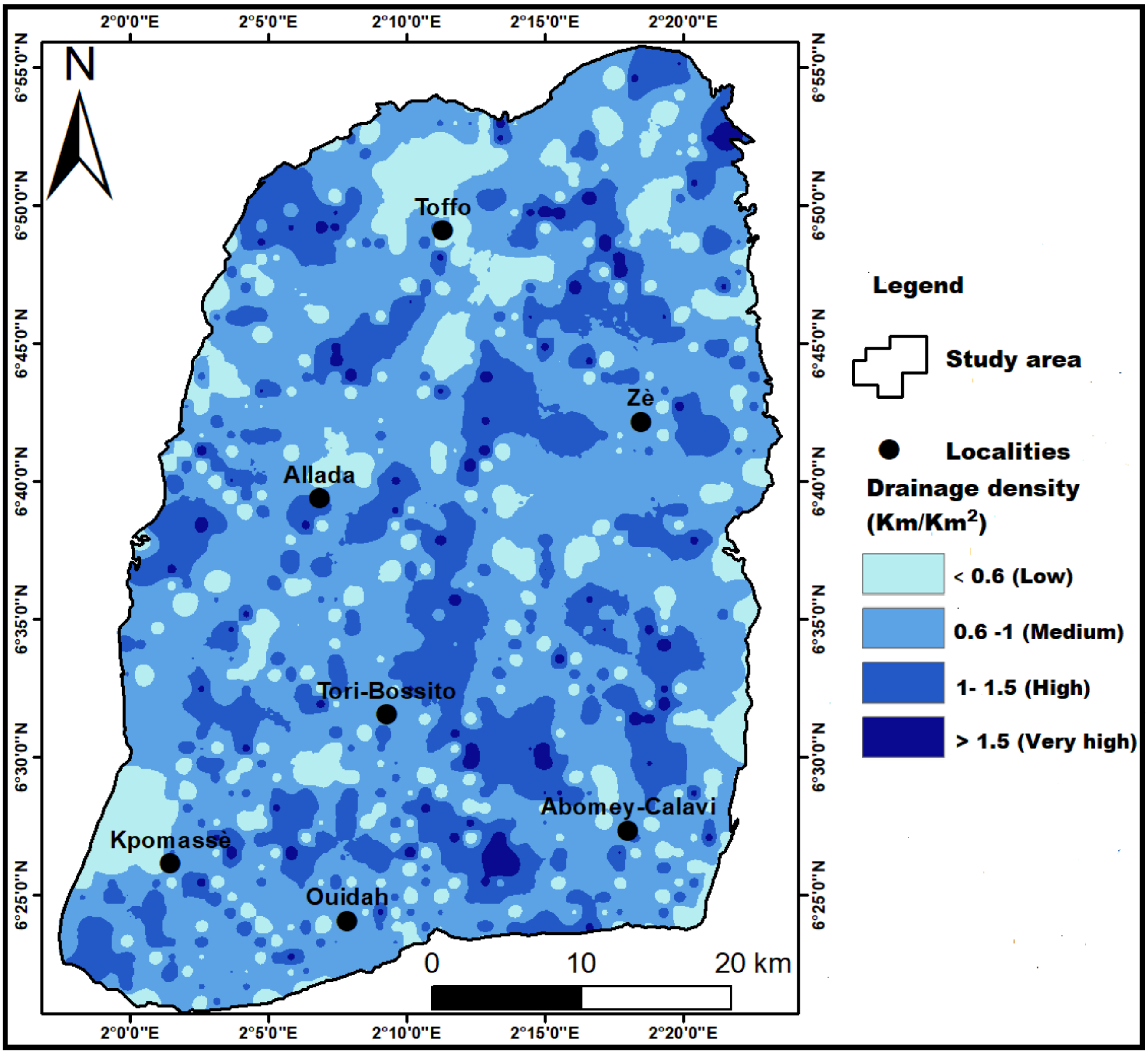

Fig. 6. Natural Stormwater Drainage Density

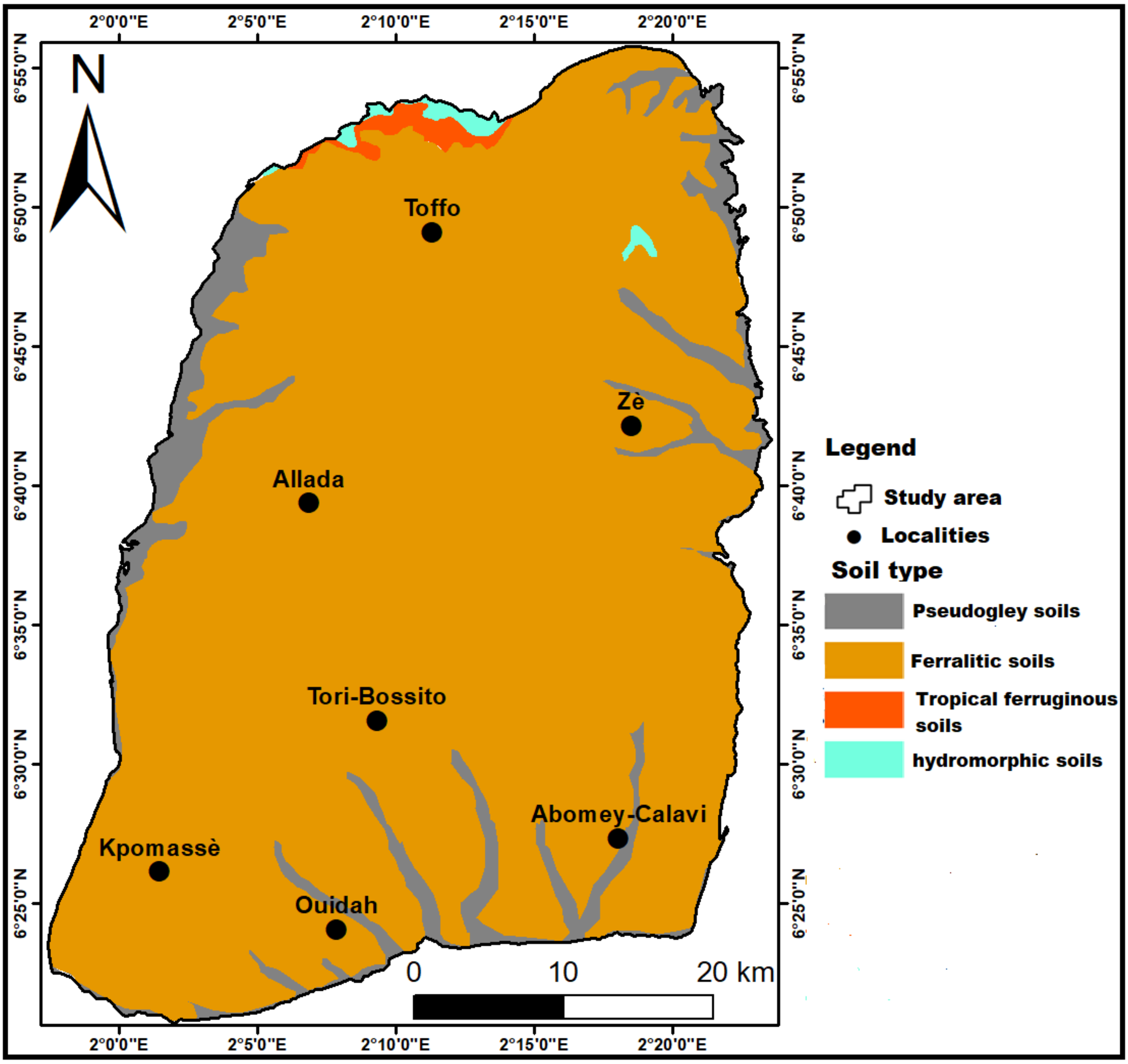

Fig. 7. Soil type on the Plateau of Allada

- **Map of the flood risk hazard on the Plateau of Allada**

The hazard map of the Allada Plateau (Figure 8) generated highlights five zones. The very low and low risk zones occupy 7.50% and 30.63% of the Allada Plateau respectively. These are essentially areas with steep slopes, low and very low drainage density and medium and high rainfall intensity. The medium class represents 36.78% of the area of the Allada Plateau and covers the large flood basins and includes the municipalities of Toffo, Allada, Zè, Kpomassè and Tori Bossito. The high and very high hazard classes are estimated at 19.14% and 5.95% respectively and cover most of the talwegs in the study area taking into account the municipalities of Ouidah and Abomey Calavi. These high and very high-risk areas are dominated by a low slope, high rainfall intensity, pseudogley type soil and ferralitic soil highly desaturated and low density drainage on the Allada plateau. The high hazard level therefore represents 25.09% of the study area.

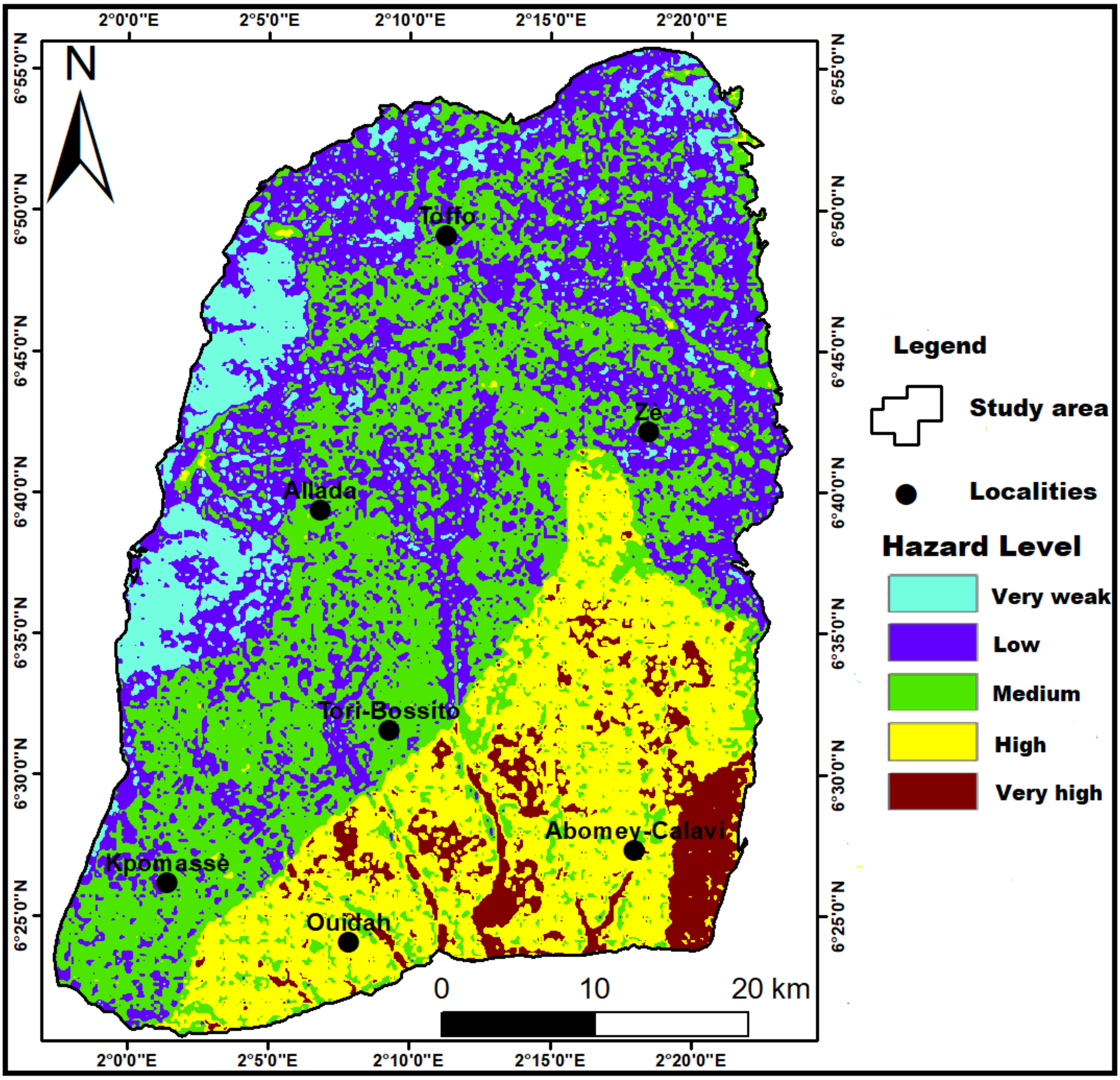

Fig. 8. Flood hazard level on the Plateau Allada

4.2 FLOOD VULNERABILITY CRITERIA ON THE ALLADA PLATEAU

The mapping of the vulnerability factor required the combination of land use and population density maps on the Allada plateau.

- **Land use**

A total of five classes were selected: built-up area, water, gallery forest, mosaic/ fallow/crop and finally plantation. The analysis of this map (Figure 9) shows that the "built" class occupies (12.77%), "water" (0.43%), gallery forest (4.64%), mosaic/crop/fallow (68.57%) and plantation (13.55%).

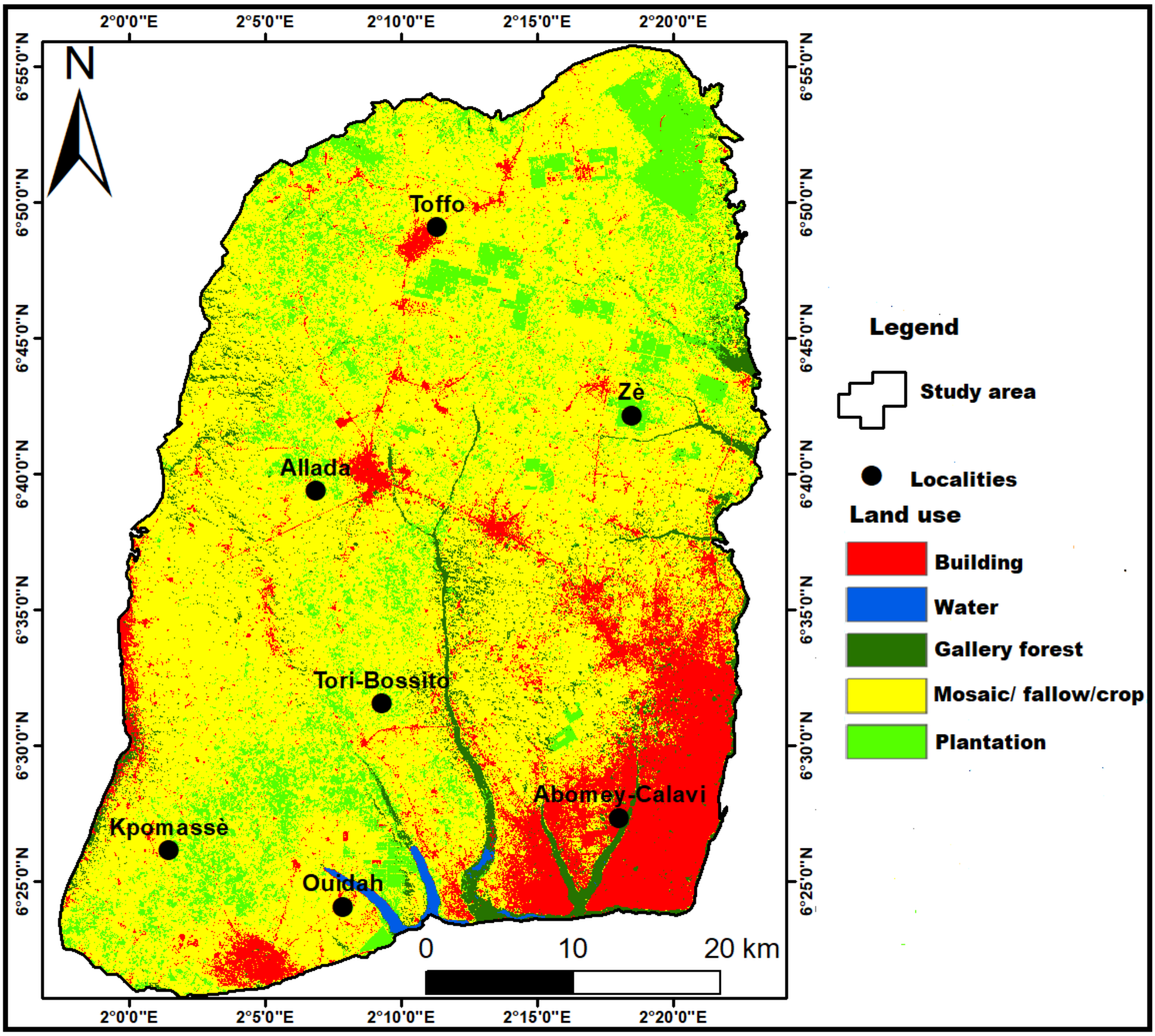

Fig. 9. Land use on the plateau of Allada

- **Population density**

The vulnerability of the populations constitutes the positive impact of flood risks on the Allada plateau. On the Allada plateau, there is a demographic surge and the anarchic installation of populations. Fig. 10 shows the population density (inhabitant/km2) on the Allada plateau by municipality. This map shows five classes: Very low (20.62%); Low (14.88%); Medium (28.98%); High (21.93%) and Very high (13.58%). Overall, the municipalities of Abomey Calavi, Ouidah and Allada concentrate the highest population densities with the High and Very High classes. The municipality of Abomey Calavi is the dominant class with a density between 428 and 1218 inhabitants/Km2. The High-density class (Ouidah and Allada) covers an overall area of 506 km2, with a density varying between 229 and 482 inhabitants/km2. The "very low" density class (Zè municipality) covers an area of 455 km2 for a density of 234.97 in habitants/km2.

- **Flood risk vulnerability map of the Allada plateau**

The vulnerability map (Figure 11) obtained by combining land use and population density highlights five zones (very low to very high). The very low and low zones cover 20.33% and 15.04% of the Allada plateau respectively. These are essentially plantation areas and mosaics of crops and fallow land, with a low population density. The middle class represents 29.25% and covers the municipalities of Toffo and Kpomassè, i.e. two out of seven municipalities (2/7). The areas covered by the high and very high vulnerability classes are 21.64% and 13.73% respectively. The analysis showed that all these areas covered by high and very high vulnerability are dominated by a high population density.

These include the municipalities of Allada, Ouidah and Abomey Calavi. A total of three municipalities out of seven (3/7) have an overall high vulnerability on the plateau of Allada

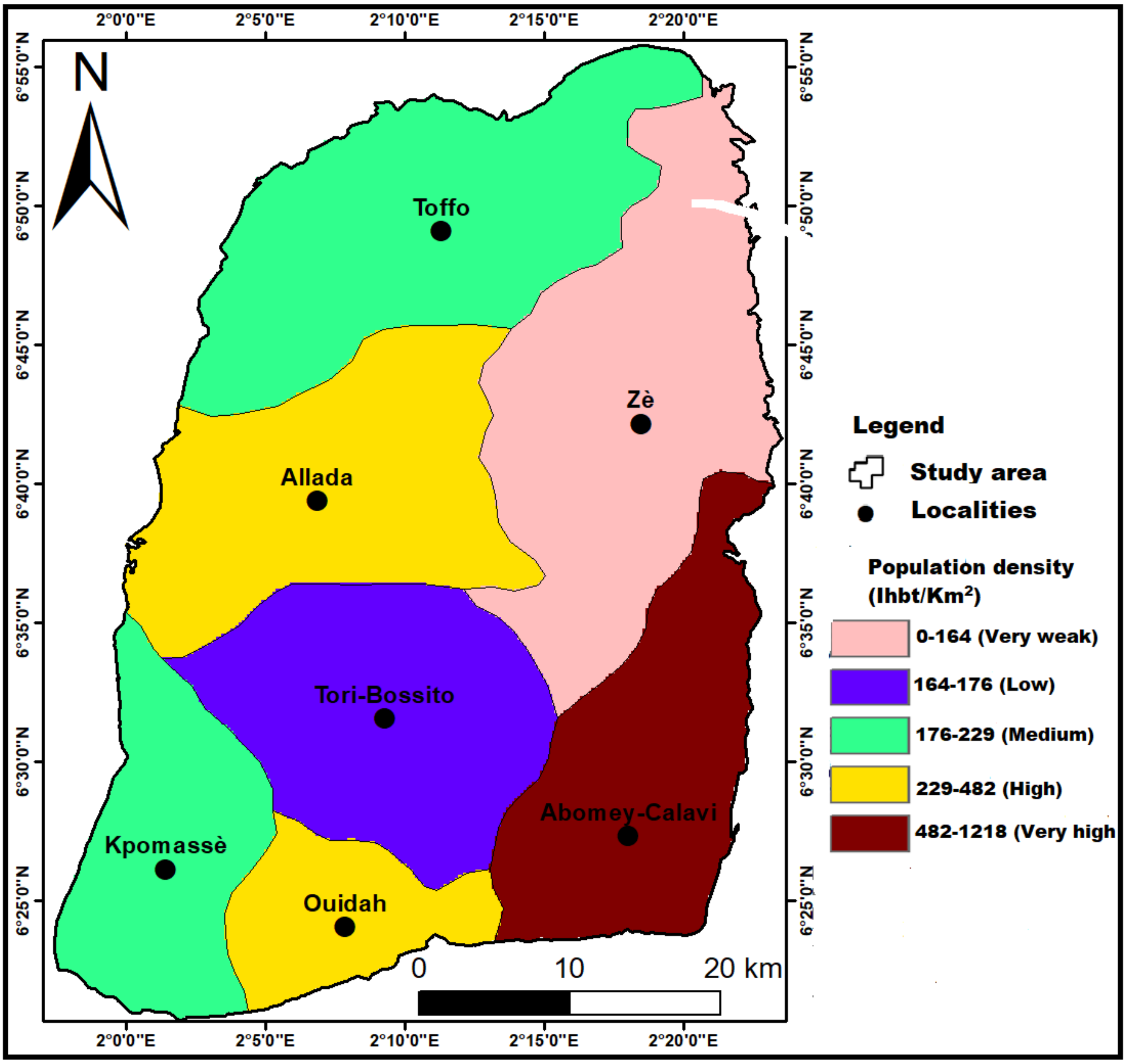

Fig. 10. Population density in the Allada plateau

4.3 FLOOD RISK MAPPING ON THE ALLADA PLATEAU

The flood risk map of the Allada Plateau obtained by linear combination of the Hazard and Vulnerability maps presented in Fig. 12, defines five levels of risk ranging from very low to very high. The areas of very low, low and medium risk of flooding cover 19.87%, 22.47% and 28.98% of the Allada plateau respectively. They are unevenly distributed and characterized by a steep slope, vegetation and plantation areas and low population density. The high and very high risk areas occupy 15.82% and 12.86% respectively (Figure 12). An overall area of high and very high risk of flooding covers 28.68% of the study area. The municipalities identified as being at high and very high risk of flooding on the Allada Plateau are Allada, Ouidah and Abomey Calavi and some of the districts of Kpomassè. The analysis of this map also shows that the buildings really play a key role in addition to the population density, flat slope and heavy rains in the risk of flooding on the Allada plateau; as well as other anthropic factors showing that the morphological level plays an aggravating role of the risk of flooding.

5 Discussions

The flood risk of the Allada Plateau was assessed using a Saaty AHP multi-criteria analysis approach, combining vulnerability and hazard. The flood risk was about 57.66% when the study summarized moderate, high and very high classes. The analysis shows that 28.68% of the study area is a high flood risk area, but from a critical analysis, most of the communal areas are high flood risk while the low and very low classes are sparsely populated and urbanized vegetation areas. Three out of seven (3/7) municipalities in the Allada Plateau are at high risk of flooding and therefore require optimal design of the company's technical solutions. The reliability of the resulting flood hazard map that gave acceptable results is based on the input parameters, historical floods and recorded data.

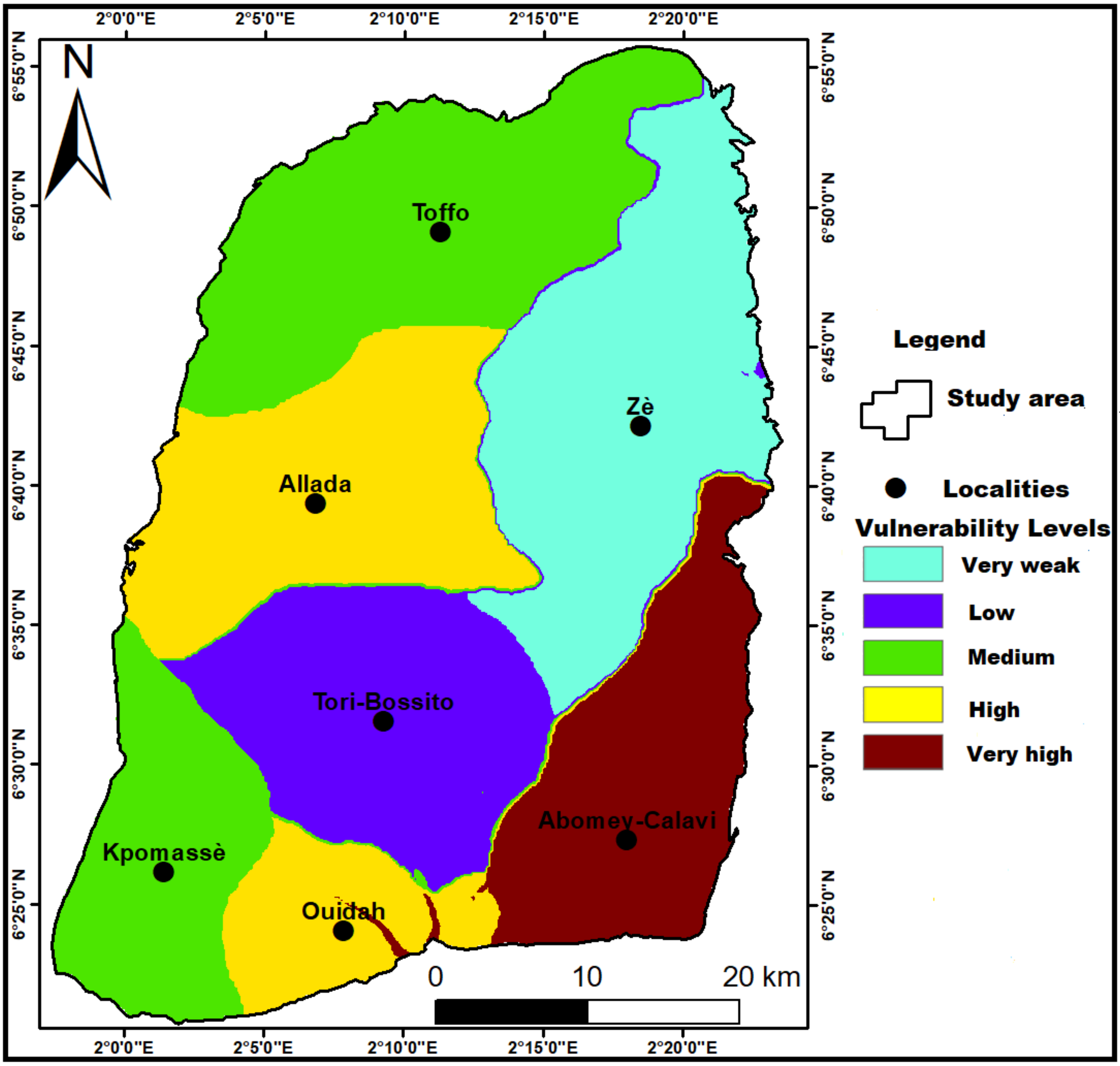

Fig. 11. Vulnerability to floods on the Allada plateau

The results of the hazard map showed that 25.09% of the Areas are at high risk, with precipitation and slope being the most important factors responsible for the occurrence of floods. The vulnerability map also showed that 35.37% of the study area is highly vulnerable to flooding with high population density and anarchic land use through buildings as important factors in flood risk.

The multi-criteria analysis carried out in the Allada Plateau through the Saaty Hierarchical Analysis Process (HAP) facilitated the combination of multi-source data, which was a real advantage in the mapping of flood risk areas. This approach is based on physical, hydrogeological and anthropogenic parameters. The parameters used in the mapping of flood risk factors include slope, drainage density, precipitation, population density, soil types and land use which are the combination of hazard and vulnerability requiring interpolations to allow their cross-referencing. The results indicate that AHP can be used as an effective method to assess and map flood risk in the GIS environment. The AHP methodology provided a better understanding of the overall contributions of a feature or indicator to the flooding process based on the weight assigned to each. However, coming from different sources, the interpolation and crossing of data in GIS at the same resolution. The normalization and weighting steps of these parameters are important to reduce bias and uncertainty in the final result. Also, The AHP method shows some failure due to subjectivity in choosing the indicator weighting value from arbitrary expert judgments ([29], [27], [9], [35]. This weakness is mitigated by the judgment consistency ratio test. Saaty, 1980 provides a threshold coherence ratio that must be less than 10% to make a coherent judgment. The value of the consistency ratio as part of this study is 3% and the study concludes that, its judgments can be considered consistent. But the use of other normalization approaches such as linear break instead of natural break can be improved for map comparison and accuracy assessment purposes. This methodological approach was inspired by various previous works [44], [45], [24], [22], [34], [39], [27], [28], [9], [8] and it is clear that flood risk is related to the combined action of many different factors under two criteria: hazard and vulnerability.

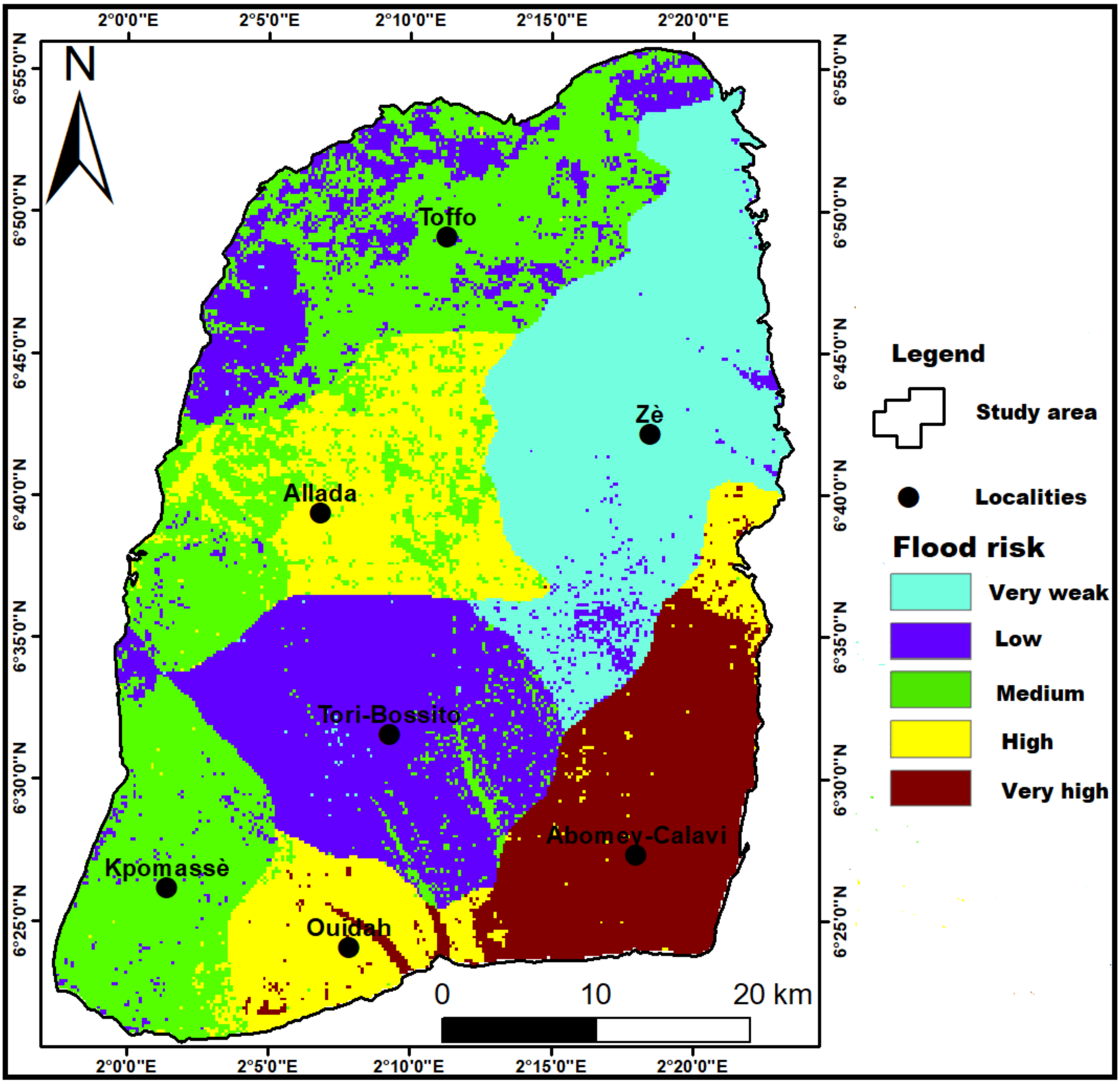

Fig. 12. Flood risk on the Allada plateau

6 CONCLUSION

The multi-criteria analysis approach used in the mapping of flood risk areas required a combination of hazard and vulnerability maps. The resulting map indicates that 28.68% of the study area is at high risk of flooding. Based on the results obtained, the Allada Plateau is at high risk of flooding. Thus, the flood risk map generated is a decision support map, which can be used as a guide for possible anticipatory measures, for better land use planning and better flood risk management in the context of climate change.

Strict measures must be taken regarding uncontrolled urbanization and the occupation of areas near rivers and storage areas. The application of multi-criteria analysis in the study of the mapping of flood risk areas of the Allada Plateau has shown its interest. The different techniques of multi-criteria analysis applied in this study have indeed allowed a better knowledge of the areas at risk of flooding on the Allada Plateau. This study has also highlighted the importance and the undeniable role of remote sensing and GIS in the evaluation of natural disasters.

ACKNOWLEDGMENT

This study was made possible by funding from the University Agency of the Francophonie (AUF), to which the authors of this article are very grateful.

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