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Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire)

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Abstract

Background: Flood is one of the most destructive natural disasters of climate change effects in West Africa. Flood risk occurrence is a combination of natural and anthropogenic factors, which calls for a better understanding of its spatial extent. The aim of this paper is to identify, and map areas of flood risk in Abidjan district.

Results: This work is based on the integration of multi-criteria data including slope, drainage density, type of soil, Isohyet, population density, land use and sewer system density within ArcGIS interface. The resulting AHP flood risk map shows that areas under high and very high flood risk covers 34 % of the study area.

Conclusion: The Analytic Hierarchy Process (AHP) method used as a multi-criteria analysis allowed the integration of several elements under two criteria, hazards and vulnerability, for flood risk assessment and mapping. Results revealed that, Abidjan district is heavily exposed to the risk of flooding. Eight out of thirteen (8/13) municipalities within the district are at a high risk of flooding which calls for decision makers to effectively develop strategies for future flood occurrences within the Abidjan district (South of Côte d'Ivoire).

Keywords: Flood risk, Multicriteria analysis, Remote sensing, Geoinformation techniques, Abidjan, Cote d'Ivoire

Background

Natural disaster is considered to be the biggest challenge that needs to be examined at global, regional and local scale. Climate change may increase the frequency, magnitude and the seasonality of extreme events such as flood, which means that concurrent flood hazard of importance to urban flood risk management, may occur more frequently in the future (Duan et al. 2015; Huong and Pathirana, 2013; Pedersen et al. 2012). Urbanization is also an important factor to increased flood risk in the cities through increasing runoffs which affect communities' downstream (Cloke et al. 2013; Duan et al. 2016). Floods are among the most devastating natural hazards in the world, claiming more lives and causing more property damage than any other natural phenomena (Duan et al. 2014; Kebede, 2012; Wang et al. 2011; Forkuo, 2011; Yahaya et al. 2010; Yalcin and Akyurek 2004; Hapuarachchi et al. 2011; Tsakiris, 2014). As a result, floods are one of the greatest challenges to weather prediction (Jeyaseelan, 2003).

In Africa, the situation is very likely to worsen as the intergovernmental panel on climate change (IPCC) has projected higher frequencies and intensities of floods and droughts (IPCC, 2007) for the continent as a consequence of climate change. Floods and flash floods cause loss of life and property damage (Musungu et al. 2012). From 1900 to 2006, floods in Africa killed nearly 20,000 people, and also affected nearly 40 million more, with estimated damages of about 4 billion USD according to the ICSU Regional Office for Africa (2007). Flood is one of the most destructive natural disasters of climate change effects in West Africa (Kouassi et al. 2008). The

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demands of the growing population and related urbanization lead to severe land use change (Franci et al. 2015) and increasing flood occurrence in West Africa.

Urban floods result from blocked or inadequate storm sewers and are due to increased urbanization (Ajin et al. 2013). Urban areas have high risk of flash flooding due to the presence of large impervious areas and sometimes inefficient drainage system (Chen et al. 2009; Huong and Pathirana, 2013; Sowmya et al. 2015). Several additional phenomena commonly contribute to urban flooding, such as limited conveyance capacity of urban channels and rivers, as well as drains and sewers and infiltration–inflow, and decades of urban development without upgrading of the drainage infrastructure (Pedersen et al. 2012). The rapid growth often results in a poorly planned urbanization making urban populations increasingly vulnerable to floods.

While the primary cause of flooding is excessive rainfall (Kim and Kim, 2014), there are many other causes resulting from human activities such as: land degradation; deforestation of catchment areas; sprawl and increased population density along riverbanks (Prasad et al. 2016; Billi et al. 2015; Mbow et al. 2008; Forkuo, 2013), poor land use planning, zoning, and control of flood plain development; inadequate drainage, particularly in cities, and inadequate management of discharges from river reservoirs.

Hence, assessing and predicting floods risk has become essential to offer appropriate solutions for flood and sustainable environmental management. Flood hazard mapping is a vital component for appropriate land use planning in flood areas and mitigation measures (Bhatt et al. 2014). It provides accessible charts and maps which can be read easily and therefore, facilitates the identification of risk areas by planners and this enable them to prioritize their mitigation efforts (Bapalu and Sinha, 2005; Forkuo, 2011; Wang et al. 2011; Ajin et al. 2013).

Flood management is necessary not only because flood imposes huge damages on the society, but for the optimal exploitation of the land and its proper management. This cannot become technically feasible without effective flood hazard and risk maps (Bhatt et al. 2014)

More recently in Cote d'Ivoire, populations have experienced increasingly important phenomena of floods, with its effects such as death, damage to property and population exodus. Heavy rainfall is the main natural hazard which causes loss of many lives; destruction of infrastructures, and the displacement of people during the rainy season in Abidjan. Statistical analysis done in 2013 shows that 26 % of the district of Abidjan is flood risk area and 21, 13, and 15 people died in 2009, 2010, and 2011 respectively due to floods (OCHA, 2013). Also the result indicates that, a total of 80,000 people live in areas that are subject to risk of flooding in the district with 40,000 people in Cocody, 12,500 people in Abobo, 10,000 in Adjame, 9,500 in Yopougon and 8,000 in Attecoube communes (OCHA, 2013). However, the use of multi-criteria evaluation approach to flood risk assessment and mapping in Cote d'Ivoire is still rare (Savane et al. 2003; Saley et al. 2005; Saley et al. 2013). Extreme rainfall data analysis for many years were based on determining break on the times series using some statistical methods such as Pettit and Buishand test (Lubes-Niel et al. 1998), application of Nicholson indices to bring out the wet and dry period in case of rainfall variability and shows general trend and interannual behavior (Brou, 2005; Savane et al. 2003; Goula et al. 2006; Kouassi et al. 2008).

Flood risk occurrence is a combination of natural and anthropogenic factors, which means that there is the need for knowledge about spatial extent of flooding areas, using multi data as drivers becomes a potential source for more reliable flood management and mitigation. For all that, Multi-criteria analysis (MCA) approach has become widely used (Wang et al. 2011; Sowmya et al. 2015) to solve complex problems and to assess flood risk. Many methods have been proposed for multicriteria decision making. Analytic Hierarchy Process (AHP) developed by Saaty (1980) is one of the best known and most widely used MCA approaches (Orencio & Fujii, 2013; Yahaya et al. 2010). AHP is used to solve a broad range of multi-criteria decision-making problems, with the pairwise comparison matrix calculating the weights for each criterion considered (Yalcin, 2008; Orencio & Fujii, 2013; Le Cozannet et al. 2013; Pourghasemi et al. 2014). AHP assumes complete aggregation among several criteria and develops a linear additive model. The uniqueness of applying AHP in different studies helps in modelling situations of uncertainty without losing subjectivity and objectivity of any evaluation measure.

Of late, considerable attention has been given to the use of AHP in natural hazard (earthquake and flood) assessment but more in flood management in various studies: (Savane et al. 2003; Yahaya et al. 2010; Cozannet et al. 2013; Orencio & Fujii, 2013; Saley et al. 2013; Chakraborty and Joshi, 2014; Pourghasemi et al. 2014; Papaioannou et al. 2015; Nejad et al. 2015). It has been shown from these series of papers that AHP has the ability to assess and map flood risk with good accuracy. However, it is based on expert opinions and thus may be subjected to cognitive limitations with uncertainty and subjectivity (Pourghasemi et al. 2014).

The significant research gap identified by this study is that recent scientific work undertaken in the district of Abidjan concentrated on rainfall variability during past and current condition as flood risk drivers within two communes of Abidjan: Attecoube and Abobo (Savane et al. 2003; Hauhouot, 2008). This is a piece-meal approach and does not provide a solution to the problem of flood occurrence within the entire district. Other studies (Kouame et al. 2013; Jourda et al. 2006; Ahoussi et al. 2013) in the district did not directly focus on flood but pointed out the inefficiency of the drainage network and impervious area which are part of the main drivers of floods. However, these studies are fragmented and did not consider the entire district and multi criteria as input to link climate change and flood occurrence, no studies have yet been undertaken to evaluate and map flood risk at Abidjan district level.

The aim of this paper was to identify, and map areas of flood risk based on several factors that are relevant to flood risks in Abidjan district. For this purpose, assessment process of flood risk was conducted under hazard and vulnerability concepts within analytic hierarchy process (AHP) framework.

Study area

The district of Abidjan is located in the south of Cote d'Ivoire between latitudes of 5° 10′ and 5° 38′ North and longitudes of 3° 4′ and 5° 21′ West (Fig. 1). It consists of thirteen (13) municipalities since 2001, ten (10) municipalities in Abidjan and three (3) others town namely Bingerville, Songon and Anyama and covers an area of approximately 2,119 km^2. The population is about 4,739,752 inhabitants in the metropolis, and 4,460,355 inhabitants in the main city (INS, 2013), which represents 20.3 % of the national population as it is in 2013. In addition, the

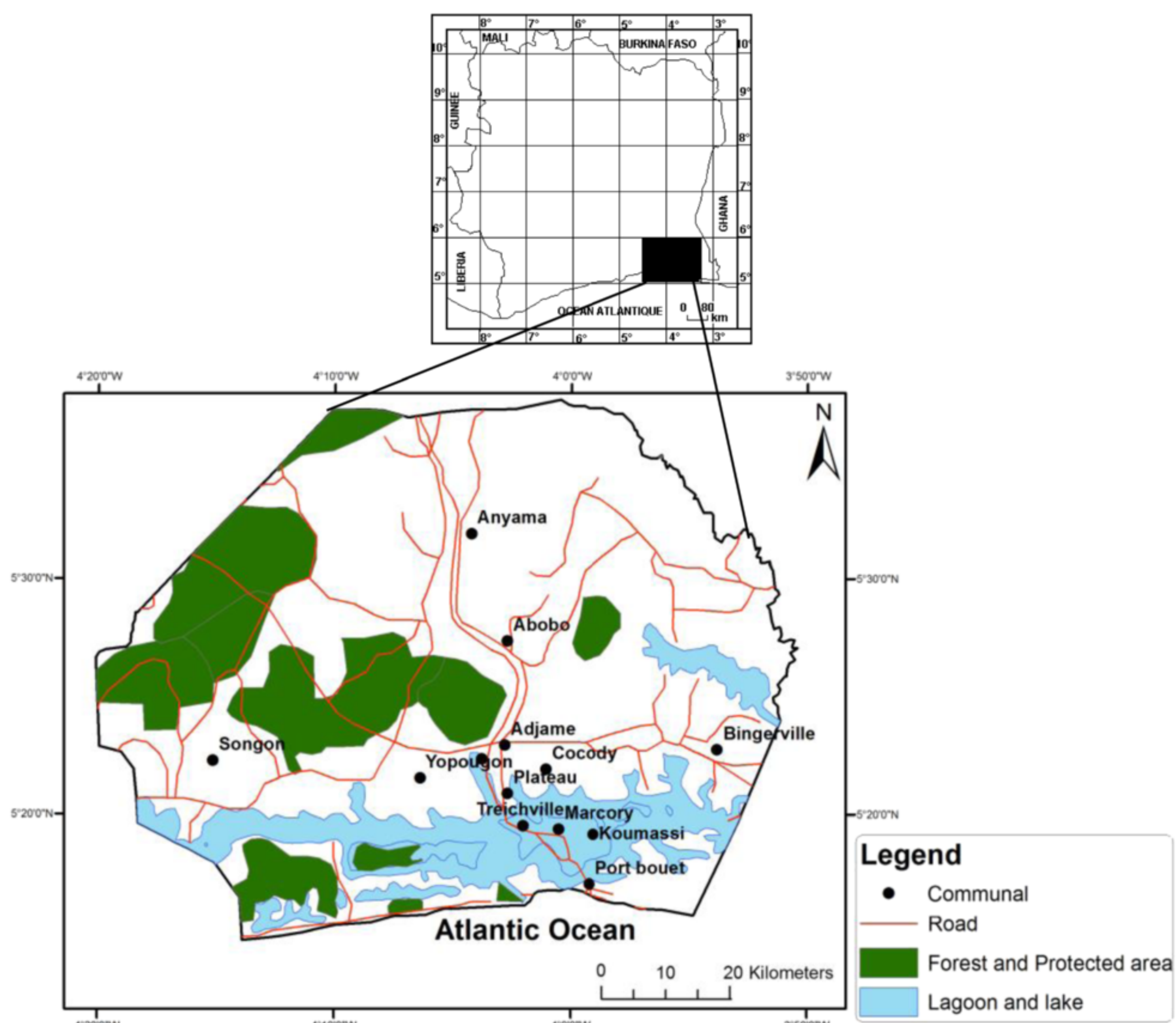

Fig. 1 Location of the study area

population is constant growth process mainly as a result of high industrialization, urbanization and the later political crisis. It is limited (Fig. 1):

- To the south by the Atlantic Ocean;
- In the southwest by the Department of Dabou;
- To the west by the Department of Grand Lahou;
- To the north by Agboville Department;
- In the south-east by the Department of Grand-Bassam;
- In the east by the Department of Alepe.

Climatic variability

According to Tapsoba (1997), the study area has an equatorial climate transition (Attieen Climat), characterized by four seasons: two dry seasons (December to April and August to September) and two rainy seasons (May to July and October to November) within the annual cycle:

- Long dry season from December to April;
- Long rainy season from May to July;
- Short dry season from July to September;
- Small rainy season from October to November.

Precipitation

The annual average rainfall of Abidjan was about 1 873 mm from 1960 to 2012 (Fig. 2).

High annual rainfall was recorded in Abidjan district during the period 1960–2012 and ranged from 2800 mm in 1963 to 1020 mm in 1990 with an average of 1910 mm. Generally, in 1960s, the annual rainfall ranged between 2000 and 3000 mm. After 1987, there has been a drop in rainfall and this has oscillated between 1500 and 2200 mm, a reduction of more than 500 mm compared to the 1960s.

Ombrothermic diagram

After completing ombrothermic diagrams which shows comparison between temperature and rainfall charts of Abidjan (Fig. 3) over the period 1961–2012; it was noted that, the temperatures are often low during the months of heavy rainfall and high during the months of low rainfall.

Also, observation of highest average monthly rainfall from 1960 to 2014 shows that June and sometimes May are the rainiest month of the District of Abidjan. Secondly, the temperature curve shows that the months of March and April are the hottest months with a monthly average temperature above 27 °C.

Analysis of the annual rainfall and the heavy rainfall month

Graphical comparison between annual rainfall and rainiest months of the Abidjan district to analyse the trend patterns from 1960 to 2012 revealed that, in general, the annual rainfall variability is based on June's amount of rainfall because it is the highest rainfall month compared to May in the series (Fig. 4).

Population growth

Abidjan is the economic capital of Cote d'Ivoire and known for its perpetual population growth characterized by continuous uncontrolled urbanization due to demographic growth which creates gap in the context of climate change and anthropogenic impact related to safe environment and healthy life (Fig. 5).

Methods

Data and material

In this study, various basic thematic layers were created from different source including map, field study, satellite image and secondary data based on multi-criteria analysis method. Using ArcGIS, Mapinfo and eCognition software tools, several maps were prepared including slope, soil, rainfall distribution, drainage density, demography, drainage system and urban structure type (land use). The drainage density and administration map were derived from the national

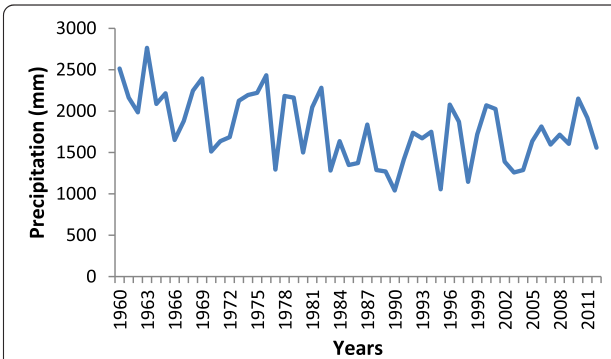

Fig. 2 Total annual rainfall variability of Abidjan from 1961–2012

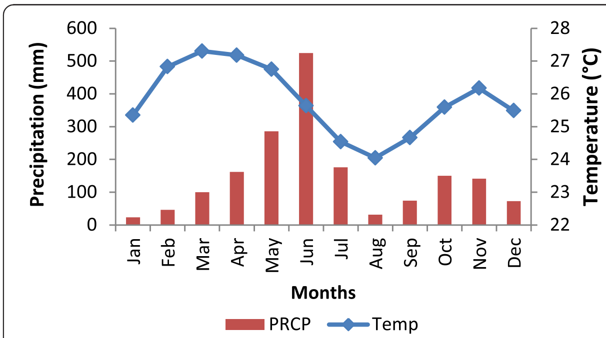

Fig. 3 Ombrothermic diagram of Abidjan District from 1981–2012

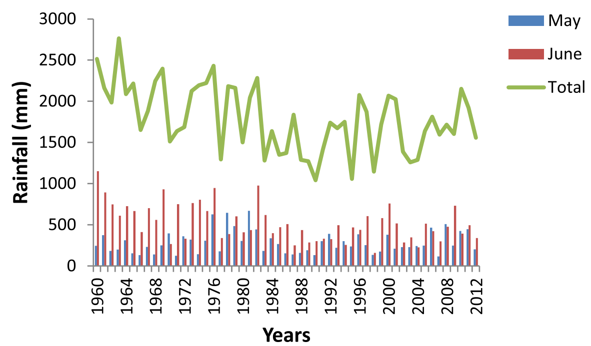

Fig. 4 Annual rainfall and heavy rain months of Abidjan from 1960–2012

center of cartography and remote sensing (CCT) and we extracted them using clip tools. Soil map was digitized based on national soil map done by ORSTOM and validated with field sample using map info software and GIS. The slope map was extracted from Aster DEM with resolution 30 m using spatial analyst tools. The rainfall distribution map was prepared from the national meteorological agency (SODEXAM) using Inverse distance weighted method (IDW). The urban structure types (land use) map was extracted from Spot 5 satellite imagery using eCognition software tools by applying oriented based image analysis. Population data obtained from the National Institute of Statistic (INS) was used to generate the population density map. Sewer system density map was also elaborated based on data collected from field and overlaid with the Water Company sewer system map.

AHP model processing

Analytical Hierarchy Process uses hierarchical structures to represent a problem and, then, develop priorities for alternatives based on the judgment of the user (Saaty, 1980) and is based on paired comparisons. Evaluation criteria and their weights must be determined according to their importance. The process consists of six steps (Saaty 1980).

- Breaking a complex unstructured problem down into its component factors
- Development of the AHP hierarchy
- Paired comparison matrix determined by imposing judgments
- Assigning values to subjective judgments and calculate the relative weights of each criteria
- Synthesize judgments to determine the priority variables
- Check consistency of assessments and judgments

One of the key points in AHP is calculation of consistency ratio (Saaty 1980). If consistency ratio is less of 0.1, then the mentioned matrix can be considered as an acceptable consistency.

However, AHP approach can be summarized in three big levels.

Hierarchic elaboration

The different levels of AHP according to Saaty, 1980; Chakraborty and Joshi, 2014; Pourghasemi et al. 2014; Papaioannou et al. 2015; Nejad et al. 2015) are: level 0: main objective, in present case flood risk map; level 1: Criteria analysis which are hazard map and vulnerability map, and level 3: element considered in each criteria characteristic based on their influence (Figs. 6 and 7).

All elements under each criterion were set based on literature and the definition of hazard (physical phenomenon, natural and non- manageable) and vulnerability (degree of susceptibility and exposure due to man-made) concepts that used in this study.

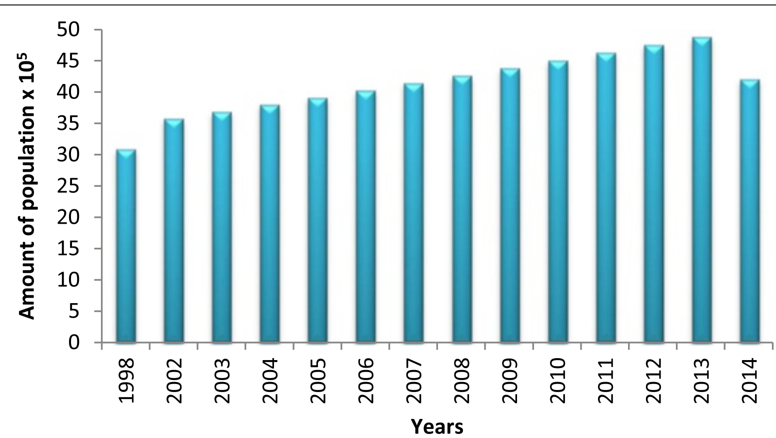

Fig. 5 Population growth of Abidjan from 1998–2014. Legend: D: drainage density; ST: soil type; S: slope; I: isohyet; UST: Urban structure type; PD: population density and DS: drainage system

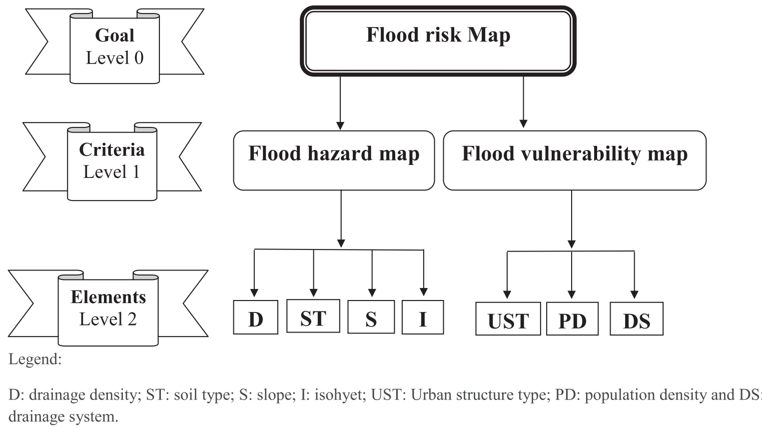

Fig. 6 AHP model use in the process flood risk map

Pairwise comparison

The binary combination is based on the scale proposed by Saaty (1980) for element comparison in Table 1. The pairwise comparison is the fundamental component of the AHP process. For each pairing within each criterion, the better option is awarded a score, again, on a scale between 1 (equally good) and 9 (absolutely better), whilst the other option in the pairing is assigned a rating equal to the reciprocal of this value. Each score records how well option "X" meets criterion "Y". Afterwards, the ratings are normalized and averaged. Ten (10) experts provide their judgment of the relative importance of one indicator against another. The pairwise comparison tables were completed by nine several experts in the field of natural disaster. Their results were normalized and examined with the Consistency Ratio test (CR).

Development and prioritization matrix

The principle of development is the following matrix:

- determine the eigenvectors (Vp) of each criterion for each item is described in equation 1.

$$Vp = \sqrt[k]{W1 \times \; .... \times Wk} \quad (1)$$

With k: number of parameters and compared Wk ratings main parameters;

- calculate the weighting coefficients (Cp), the formula is given in equation 2.

$$Cp = \frac{Vp}{Vp1 + \; ..... + Vpk} \quad (2)$$

The sum of Cp of all parameters of a matrix must be equal to 1 (one).

- normalize the matrix by dividing each element by the sum of a column of the column ;

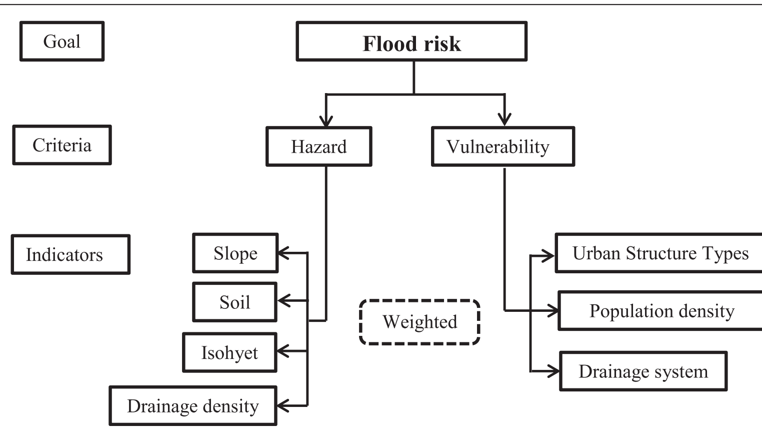

Fig. 7 Hierarchy of flood risk assessment

Table 1 Saaty scale for various elements comparison Saaty (1980)

Scale	Judgment of preference	Description
1	Equally important	Two factors contribute equally to the objective
3	Moderately important	Experience and judgment slightly favour one over the other
5	Important	Experience and judgment strongly important favour one over the other
7	Very strongly important	Experience and judgment strongly important favour one over the other
9	Extremely important	The evidence favouring one over the other is of the highest possible validity
2, 4, 6, 8	Intermediate preference between adjacent scales	When compromised is needed

- averaging each line to determine the priority vector [C];
- multiply each column of the matrix by the priority vector corresponding there to determine the overall priority [D];
- Divide each global priority by the priority vector corresponding to it to determine the rational priority [E];
- Determine the maximum Eigen value (λmax) by equation 3:

$$\lambda \max = \frac{[E]}{k} \tag{3}$$

- Calculate the consistency index (CI) expressed by equation 4:

$$CI = (\lambda \max - k)/(k-1) \tag{4}$$

- Determine the consistency ratio (CR) using equation 5. The ratio of coherence can be interpreted as the probability that the croak is completed in a random manner. In fact, the responses often have a certain degree of incoherence. The AHP method does not require that judgments are consistent or transitive, indeed, Saaty (1980) has defined the value of consistency ratio. In the case where the value of consistency ratio is less than 10 %, the judgment is consistent and when it exceeds 10 %, the assessments may require some revisions.

$$CR = \frac{CI}{RI} \tag{5}$$

(RI) is the random index. Values (RI) are shown in Table 2.

AHP hazard map

Hazard is considered a physical phenomenon, natural and non- manageable, occurrence data and intensity that can cause damage by overflow stream and the extension of the field in the water flood. Hazard refers also to hydro climatic phenomena and their impact on the flow of water. Geomorphological characteristics including slope, drainage density, soil types (Meraj et al. 2013) and rainfall (because it is the intense rainfall that triggered flooding) are the various factors taken into account in the mapping of the hazard. The hazard map will show all areas susceptible to be flooded. Crossing parameters will map the spatial extent and potentially exposed areas to climatic hazards that can cause flooding. Based on Saaty scale, different weight has been attributed to determine hazard. See below, an example of calculation of the eigenvector (Vp) and the weighting coefficient (Cp) of the drainage density. The weight assign to each element to determine Hazard are in Tables 3 and 4.

$$\text{Vp} = \sqrt[4]{1 \times 3 \times (1/3) \times 1/5} = 0.67 \quad \text{and} \quad \text{Cp} = \frac{0.67}{4.95} = 0.13$$

The relative hazard map is obtained by the given formula:

$$Hazard\ index = 0.13 \times D + 0.08 \times TS + 0.26 \times S + 0.52 \times I \tag{6}$$

where D = Drainage density; TS = Type of Soil, S = slope and I = Isohyet (rainfall)

AHP vulnerability map

Vulnerability expresses the level of foreseeable consequences of a natural phenomenon on issues (Mate, 2001) and on the other hand is the most crucial component of risk in that it determines whether or not exposed to a hazard constitutes a risk (Ouma & Tateishi, 2014). Flood vulnerability mapping is the process of determining the degree of susceptibility and exposure given place

Table 2 Random index matrix of the same dimension (Saaty 1980)

Number of criteria	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Number of criteria = number of parameters compared

Table 3 Hazard matrix

	D	Ts	S	I	V_P	C_P
D	1	3	1/3	1/5	0.67	0.13
Ts	1/3	1	1/3	1/5	0.38	0.08
S	3	3	1	1/3	1.31	0.26
I	3	5	3	1	2.59	0.52
Sum	7.33	12	4.66	1.73	4.95	1

to flooding. These issues include people, goods and socio-economic activities likely to be affected both quantitatively and qualitatively by a natural phenomenon. In this study, the vulnerability to flooding consists of three criteria: population density, drainage system and land use. The weight assign to each element to determine the vulnerability extent are in Table 5.

The relative map of vulnerability of the land to flood is obtained from the formula:

$$Vulnerability\ \ index = 0.26 \times UST + 0.64 \times PD + 0.1 \times DS \quad (7)$$

where UST = Urban Structure Types; PD = Population Density, DS = Drainage System

Mapping of flood risks

A flood risk map is a result of the combination of two components: Hazard and vulnerability (Ouma & Tateishi, 2014; Yagoub, 2015). This model is suitable for most natural hazards and is given by this equation 7:

$$Risk = Hazard\ \ index \times Vulnerability\ \ index \quad (8)$$

In this study, weight were assigned to the different thematic indicators classes and layers based on their relative influence and contribution to the hazard and vulnerability. The overlay technique was employed to the indicators to determine hazard and vulnerability first of all and by crossing hazard and vulnerability to obtain the goal which is flood risk area identification and zoning. All processes were done in ArcGIS using raster calculator in spatial analyst tools.

Results and discussion

Hazard map

The hazard map obtained highlights five areas as shown in Fig. 8. The very low and low classes cover 22.42 % and 30.67.5 % respectively of Abidjan. It is essentially areas with high slope, low drainage density and low precipitation amount. The medium class represent 15.41 % include Yopougon and Abobo municipalities but is around areas of high and very high hazard. The classes of high and very high hazard are estimated to 15.34 % and 16.16 % respectively cover most of Abidjan municipalities (Adjame, Plateau, Cocody, Treichville, Koumassi, Port-Bouet, marcory, Attecoube and Bingerville) numbering nine out of thirteen (9/13) municipalities. All these areas are within high and very high hazard zones and are dominated by low slope, significant occurrence of rainfall, tertiary sand, ferralitic soil strongly desaturated and low drainage within the Abidjan district.

Vulnerability map

The vulnerability map obtained by combining land use, population density and drainage system highlights five areas (very low to very high) as shown in Fig. 9. Very low and low classes cover 24.34 % and 21.63 % respectively of Abidjan. It is essentially areas with vegetation, cropland, less population density, good drainage system, industrial area and high residence area. Medium class represents 29.89 % and covers most of Abidjan municipalities (Anyama, Plateau, Treichville, Port-Bouet, Marcory, and Bingerville) around six out of thirteen (6/13) municipalities. Areas covered by high and very high classes of vulnerability are 14.59 % and 09.55 % respectively. Analysis showed that all these areas covered by high and very high vulnerability are dominated by poor drainage systems, high population density and impervious area (Abobo, Yopougon, Attecoube, Koumassi and some area in Cocody) within the Abidjan district.

Flood risk

The risk of flooding resulting map in Fig. 10, defines five levels of risk, ranging from very low to very high. Areas with very low, low and medium risk of flooding cover respectively 5.23 %, 24.37 % and 36.31 % of Abidjan. They are unevenly distributed and characterized by high slope, vegetation and cropland areas and low population

Table 4 Normalization of hazard matrix

	D	Ts	S	I	∑ of rows	[C]	[D] = [A]* [C]	[E] = [D]/[C]	λmax	CI	CR
D	0.14	0.25	0.07	0.12	0.58	0.15	0.58	3.87			
Ts	0.04	0.08	0.07	0.11	0,3	0.08	0.32	4	**4.09**	**0.03**	**0.03**
S	0.41	0.25	0.21	0.19	1.06	0.26	1.12	4.31			
I	0.41	0.42	0.64	0.58	2.05	0.51	2.14	4.20			
Sum	1	1	1	1	3.99	1		16.38			

*mean multiply

Table 5 Vulnerability matrix

	LU	PD	DS	V_p	C_P	λ_{max}	CI	CR
LU	1	1/3	3	1	0.26			
PD	3	1	5	2.47	0.64			
DS	1/3	1/5	1	0.4	0.1	**3.03**	**0.02**	**0.03**
Sum	4.33	1.53	9	3.87	1			

density. Areas with high and very high risks cover 19.97 % and 13.92 % respectively. An overall area of high and very high risk of flooding covers 34 % of the study area. Municipalities identified to be at high and very high risk of flooding within the Abidjan district are Abobo, Yopougon, Adjame, Attecoube, Koumassi, Port-bouet, Marcory, Treichville and some area of Cocody. The analysis of this map show also that the urban structure types play really a key role in addition to population density,

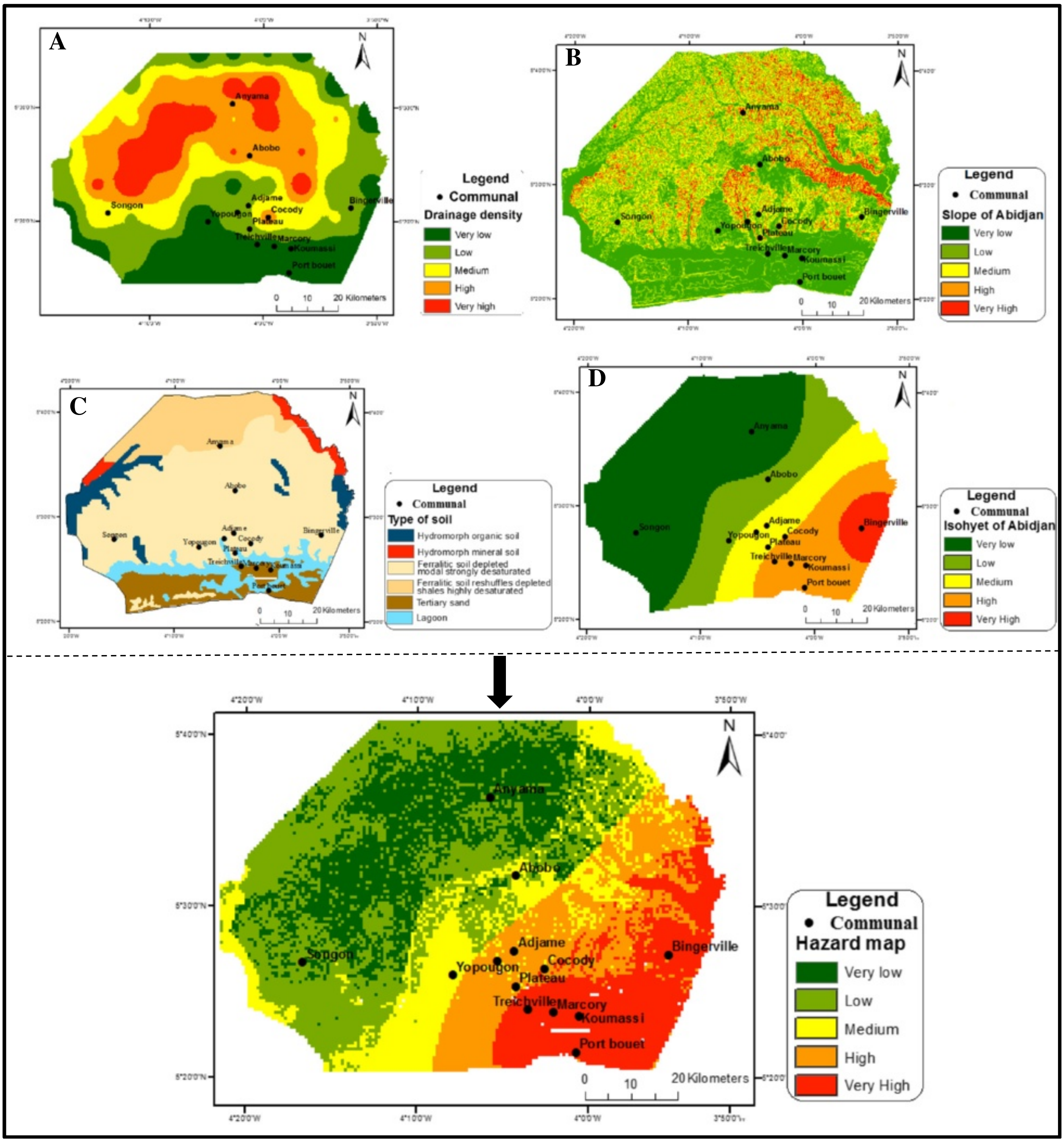

Fig. 8 Hazard map of Abidjan. **a** Drainage density map, **b** Slope map, **c** Type of soil map and **d** Isohyet map

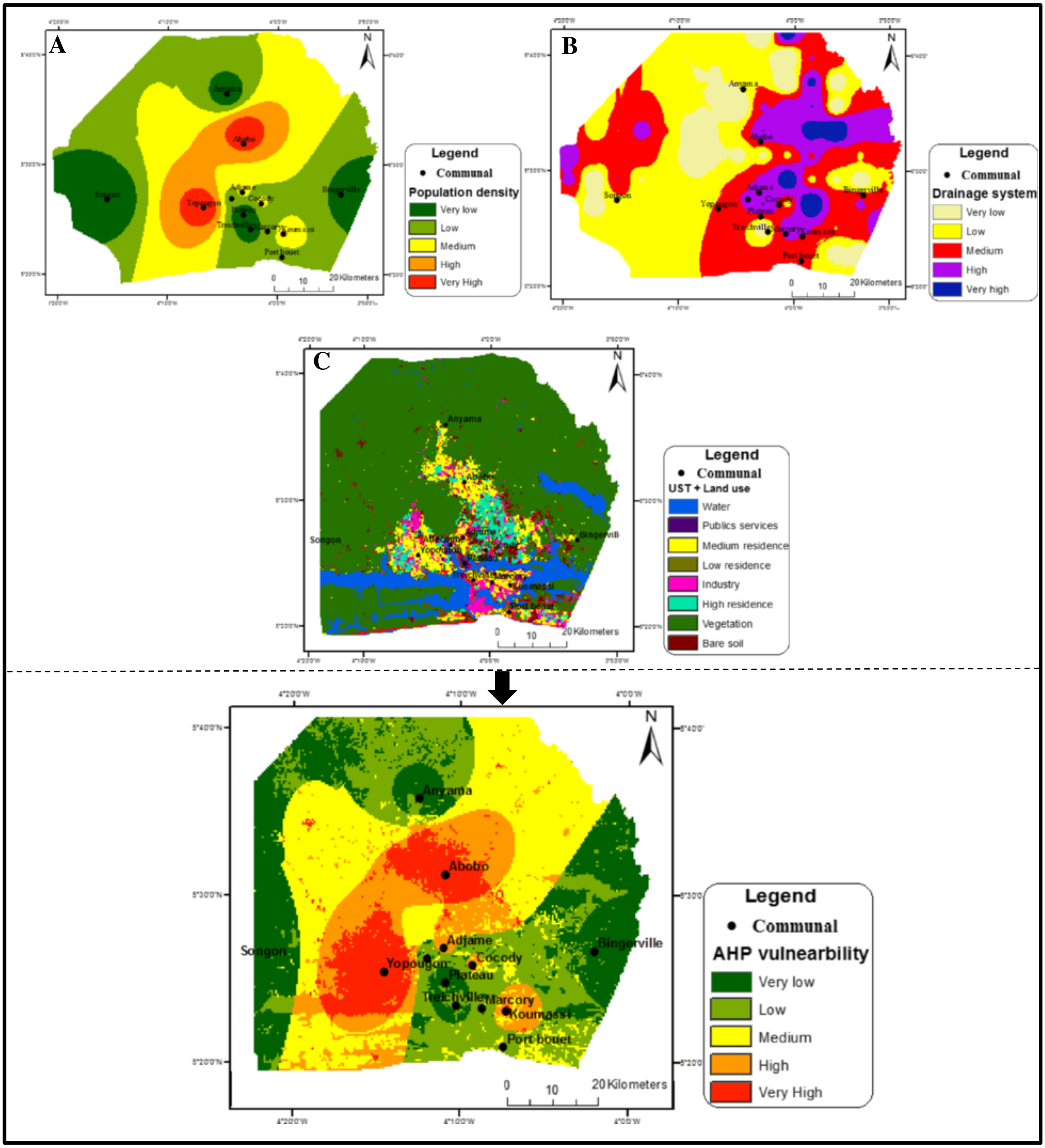

Fig. 9 Vulnerability map of Abidjan. **a** Population density map, **b** Drainage system map and **c** Urban Structure Types

flat slope and heavy rainfall into the risk of flooding in Abidjan; as well as other anthropogenic factors (uncontrolled urbanization) showing morphology level play an aggravating role in the risk of flooding.

Discussion

Abidjan district flood risks was evaluated using multi-criteria analysis approach specifically AHP, combining vulnerability and hazard assessment. The flood risk was around 70 % when the study summed moderate, high and very high classes. The analysis shows that 34 % of the study area is flood risk zone, but from critical analysis most of the communal areas are high flood risk areas whiles the low and very low classes are vegetation areas with few population and urbanization. Eight out of thirteen (8/13) municipalities of Abidjan district are at a

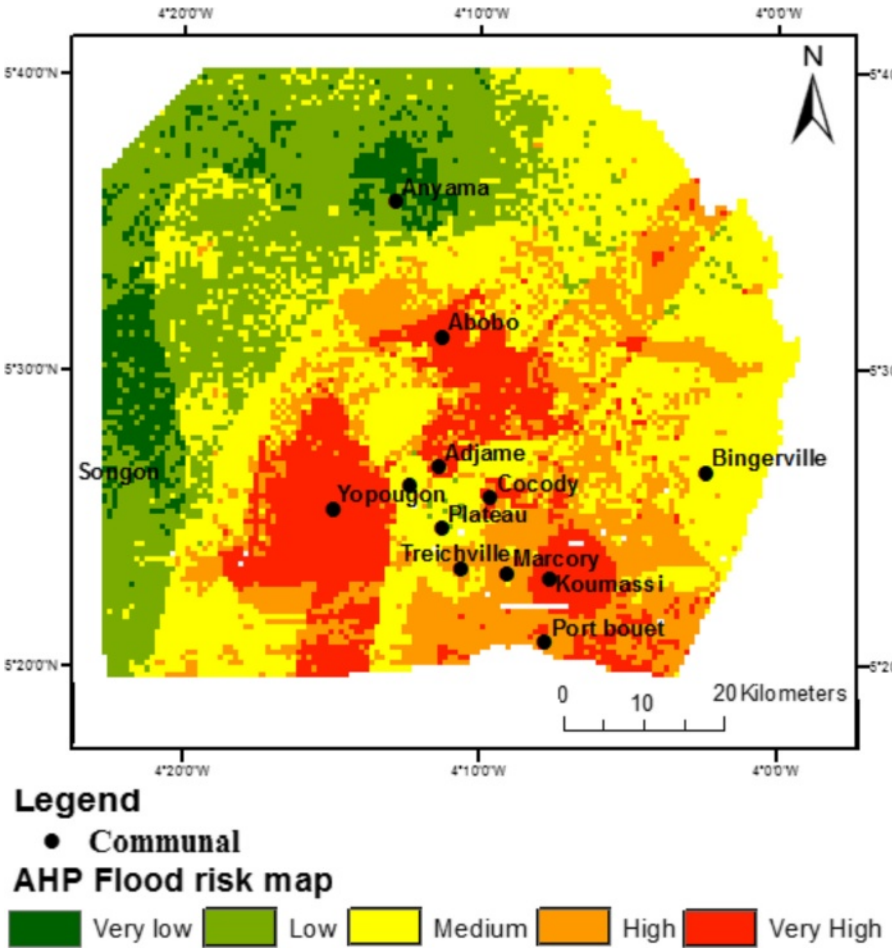

Fig. 10 Flood risk map of Abidjan

high risk of flood and therefore need optimal design of technical solutions from society. The reliability of the resulting flood risk map which gives acceptable results is based on input parameters, historical and recorded flood data. Results from the hazard map showed 32 % of the area as high hazard risk with rainfall and slope being the most significant causative factors in flood occurrence. The vulnerability map also showed 24 % of the area as highly vulnerable to flood with population density and land use through urban structure types as relevant factors in flood risk.

Multi-criteria analysis (AHP) adopted for this study within Abidjan district facilitated multi-source data combinations, which constituted a real advantage. The method is based on physical, hydrogeological and anthropogenic parameters. The parameters used in the flood risk map include slope, drainage density, soil, rainfall, system of evacuation, demography and land use which are the combination of hazard and vulnerability require interpolations to allow their crossing. Results indicated that AHP can be used as an efficient method to assess and map flood risk in GIS environment. AHP methodology allowed a better understanding of all the element or indicator contributions in flood process based on weight given to each of them. However, coming from different sources, interpolating and crossing data in GIS at the same resolution are factors of some bias during the processing and analysis. Normalization and weighted steps of these parameters are important to reduce bias and uncertainty in the final result. Also, AHP method shows some failure due to the subjectivity in choosing the value of the indicator weighting from arbitrary judgments of experts (Papaioannou et al. 2015). This weakness is reduced by the consistency ratio test of judgments. Saaty, 1980 provides a consistency ratio threshold which must be less than 10 % to make a coherent judgment. The value of consistency ratio as part of this study is 3 % and the study concludes that, its judgments can be considered coherent.

But the use of other standardization approach such as linear instead of natural break (Jenks) can be improved for map comparison and accuracy assessment purposes.

This methodological approach was inspired by various previous work (Saley *et al*., 2013; Saley et al. 2005; Mbow *et al*., 2008; Cozannet *et al*., 2013; Orencio, and Fujii, 2013; Chakraborty and Joshi, 2014; Pourghasemi *et al*., 2014; Papaioannou *et al.*, 2015; Nejad *et al*., 2015) and it is clear that the risk of flooding is linked to combined action of many different factors under two criteria: hazard and vulnerability. However, the results can be improved by the development of urban structure types (UST) through oriented based image analysis (OBIA) method using high-resolution images (Ikonos, RapidEye, QuickBird) to raise classification details on urban morphology with good accuracy. Hydrologic modeling in 2D or 3D for efficient processing and management of floods (Zazo *et al*., 2015) can be added.

Conclusion

The multi-criteria analysis approach used in mapping areas at risk of flood required a combination of hazard map (slope, drainage, soil type and isohyet) and vulnerability map (population, sewer system density and UST). The resulting map indicates that, 34 % of the study area is of high flood risk. In view of the results obtained, the Abidjan district is heavily exposed to the risk of flooding. Thus, this resultant map can serve as a guideline to decision makers for potential anticipatory measures, better land use planning and flood risk management under climate change.

Strict measures needs to be taken concerning the uncontrolled urbanization and the occupation of areas that has proximities of rivers and places of clogged water passages to be implemented by policy makers in order to prevent more significant damages. The identified areas as a high risk require more detailed mapping with the use of high spatial resolution satellite images to constitute a research perspective that can improve and refine the results obtained. This study also put in evidence the reliability and the irrefutable role play by geoinformation techniques in natural disaster assessment which requires the contribution of multi-source data.

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Authors' contributions
JHD collected data from various sources, performed the assessment and drafted the manuscript. BMS, SNO, JS, FKK provided skills development, comments and suggestions during data generation, analysis, and results interpretation. MT provided software and methods guidance to develop urban structure type (UST) classification. AK and LYA helped to draft the manuscript. All authors read and approved the final manuscript.

Competing interests
I declare and certify that this research article is for pure academic purpose. In fact, it is one specific objective of my PhD research. Therefore, there is a non-financial competing interest.

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