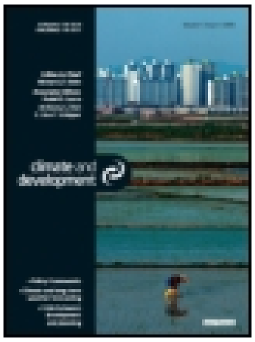

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RESEARCH ARTICLE

Mapping urban residents' vulnerability to heat in Abidjan, Côte d'Ivoire

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The land use/land cover of the district of Cocody in Abidjan, Côte d'Ivoire, is under substantial pressure associated with ´fast urbanization. This study conducts a detailed analysis of the impact of the changing land use/land cover in Cocody by assessing inhabitants' social vulnerability to heat. The approach was based on integrated methods: remote sensing-based analysis of urban land cover helped to analyze the urbanization dynamic, while indicator-based analysis, through the integrated theoretical MOVE framework, helped to define vulnerability and identify indicators. Both methods combined allowed an analysis of the social vulnerability of Cocody inhabitants to extreme heat conditions. The results reveal that Cocody is experiencing rapid land use/land cover change dominated by rapid growth of buildings and a noticeable decrease in the natural environment. Cocody is highly vulnerable to extreme heat conditions, which could be aggravated by its increasing population, with a high percentage of children under five years of age (11.31%). Creating more green spaces is therefore recommended in the more susceptible areas to counter the harmful effects of the changing climate.

Keywords: human security; vulnerability; green space; urbanization; heat

1. Introduction

A rapid population expansion is being observed in urban areas worldwide. This urbanization trend is continuing and is likely to persist in the coming decades (UN, 2014a). Although Africa has the least urbanized centres in the world, the number of urban inhabitants is expected to double by 2030 (UN 2014b). As a result, community planning faces the challenge of how to achieve urban sustainable development. Urbanization prevents the ecosystem from performing its natural functions (MA, 2005). Moreover, it has quickly transformed the ecosystem into infrastructures and buildings that increase thermal-storage capacity (Luber & McGeehin, 2008). Thus, the potential for evaporative cooling is reduced as a result of less vegetated surfaces (UNFPA, 2009). This condition is worsened by climate change (Wilby, 2008). IPCC (2012) reported a medium confidence of the occurrence of a significant temperature increase of warmest days and coldest nights. Moreover, heat (a hot environment) can have a notable impact on human mortality and morbidity (Depietri, Renaud, & Kallis, 2012). A recent study across England, for instance, showed that those who live closer to a green environment had 25% lower all-cause death rates (Mitchell & Popham, 2008). With the increase in temperature, public green spaces in urban areas are playing a vital role by providing a healthy living environment.

Located in sub-Saharan West Africa, Côte d'Ivoire is not exempt from this urbanization trend. The percentage of urban inhabitants is expected to rise from 50.1% in 2010 to 56.6–62.8 by 2020–2030 (UN-Habitat, 2008). This leads to the question of whether urbanization policies are taking into account natural resources to help mitigating the harmful effects of the climate in Côte d'Ivoire and especially in the economic capital Abidjan. Although heat is a natural phenomenon, vulnerability of a certain area to heat can arise from a combination of socio-economic and environmental factors that vary spatially from one area to another and determine how people will be affected (Mendel, 2006; Okayo, Odera, & Omuterema, 2015). The definition of vulnerability varies so widely that the term becomes almost useless in the interdisciplinary context without further specification (Füssel, 2009). According to IPCC (2012), vulnerability is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes". Concerning climate change, vulnerability refers to the state of susceptibility to harm from exposure to climate hazards, and the ability of a unit of

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analysis to cope with, and recover from, such exposure as well as manage incremental and long-term change in climate (UNDP, 2010). Different views on analyzing vulnerability exist. These views are reflected in various analytical concepts and models of how to conceptualize the vulnerability. Different frameworks have been used to develop indicators for assessing vulnerability (Kumar, Paul, Reddy, Rao, & Reddy, 2014; Blaikie, Cannon, Davis, & Wisner, 2007). For instance, the Conceptual Framework to Identify Disaster Risk considers disaster risk as a function of hazard, exposure, vulnerability and capacities. This framework recognizes vulnerability as a component of risk and differentiates between exposure, vulnerability and capacities (Birkmann et al., 2013). However, since vulnerability is social, this framework is deficient because it separated exposure as well as capacity and measures from vulnerability. Concerning Bohle's double structure of vulnerability, it describes vulnerability as a concept with both external and internal sides. The strength of the double structure of vulnerability is that it recognizes exposure and coping capacities as determinants of vulnerability but excludes sensitivity, which addresses the impact side of the hazard. Several vulnerability frameworks exist and their strengths and weaknesses have well been describes elsewhere (Birkmann et al., 2013). The MOVE framework (Methods for the Improvement of Vulnerability Assessment in Europe) is an integrative and holistic framework to systematize and assess vulnerability, risk and adaptation. It is a thinking and heuristic tool, which outlines key factors and different dimensions that need to be addressed when assessing vulnerability in the context of natural hazards and climate change (Welle et al., 2014). It bridges the gap between the different concepts used within the disaster risk management (DRM) community and climate change adaptation (CCA) research. This MOVE framework which defines vulnerability in terms of exposure, susceptibility/fragility and the lack of resilience could, therefore, be more relevant in assessing urban inhabitants' social vulnerability.

Over the years, many studies on climate effects have been carried out in Cote d'Ivoire, especially in Abidjan (Kablan, Dongo, & et Coulibaly, 2017; Danumah et al., 2016; Konate et al., 2016; Dongo, Cissé, & et Biémi, *2008*; Hauhouot, 2008). However, the factors that increasingly acting on people's vulnerabilities and the respective socio-economic conditions have not been assessed yet. Moreover, an in-depth multi-criteria approach to assess heat has not been conducted to date. Those who have considered a multi-criteria approach to assess and map vulnerability and risk to natural hazards (Danumah et al., 2016) have failed to incorporate societal aspects in the definition of vulnerability to flood. The current study conducted in Cocody, a district of Abidjan, Côte d'Ivoire, aims at closing this gap. The main objective of this study is to assess the social vulnerability of the inhabitants of Cocody to heat in the context of rapid urbanization and lack of green spaces.

2. Materials and methods

2.1. *Study area*

The study has been conducted in Cocody, 1 of the 10 districts of Abidjan located between the latitudes 5°18' and 5°26' N, and the longitudes 3°53' and 4°1' W. Located on the eastern side of Abidjan, Cocody district has an area of 122.64 km^2 (20.8% of Abidjan total size). It borders the Abobo district in the north, the Ebrie lagoon in the south, the Adjamé district in the west and the town of Bingerville in the east. The course of the eastern border is not very clear, hence there is widespread confusion on which areas close to it belongs to Bingerville and Cocody, respectively (Figure 1).

This district has been selected because it is one of the wealthiest districts in Abidjan with a large amount of land that has not yet been built and which attracts developers. Cocody reflects the urban expansion of Abidjan to a great extent. With the ongoing climate change that drives an increase in temperature, a study that will assess how residents could be vulnerable to heat could be relevant for this district to help for urban management and planning. Cocody has also been selected because most of the background data that needed to assess the vulnerability was updated and available. The 1998 census states a population of 251,741 inhabitants (RGPH, 1998), while the Institut National de Statistique (National Standard Bureau) projection for 2014 states a population of 400,322 inhabitants. Cocody is among the best-planned and most wealthy districts of Abidjan with relatively expensive property and a relatively high standard of living, accommodating the President and most of the government officials. However, there are also some poor areas, such as Cocody-Anono, Blockauss and M'Badon, which are thought not to belong to Cocody district but as stand-alone villages. That is to highlight that the district of Cocody encompasses all social classes which also guided our choice of the area.

2.2. *Mapping the dynamics of land use/cover*

Mapping the dynamics of the urbanization in Cocody has gone through the pre-processing (classification) of the satellite images and the land use/cover map validation to the statistical computing of the change detection. Three Landsat satellite images from the USGS site (http://earthexplorer.usgs.gov) have been obtained for the years 1989, 2000 and 2014. Image pre-processing was done using ArcGIS 10.1. The sensors TM (Landsat 4) and ETM+ (Landsat 7) showed seven spectral bands, while the OLI_TIRS (Landsat 8) had 11 bands. For each satellite image, all the bands were chosen to create a composite band. The images were subsequently georeferenced by

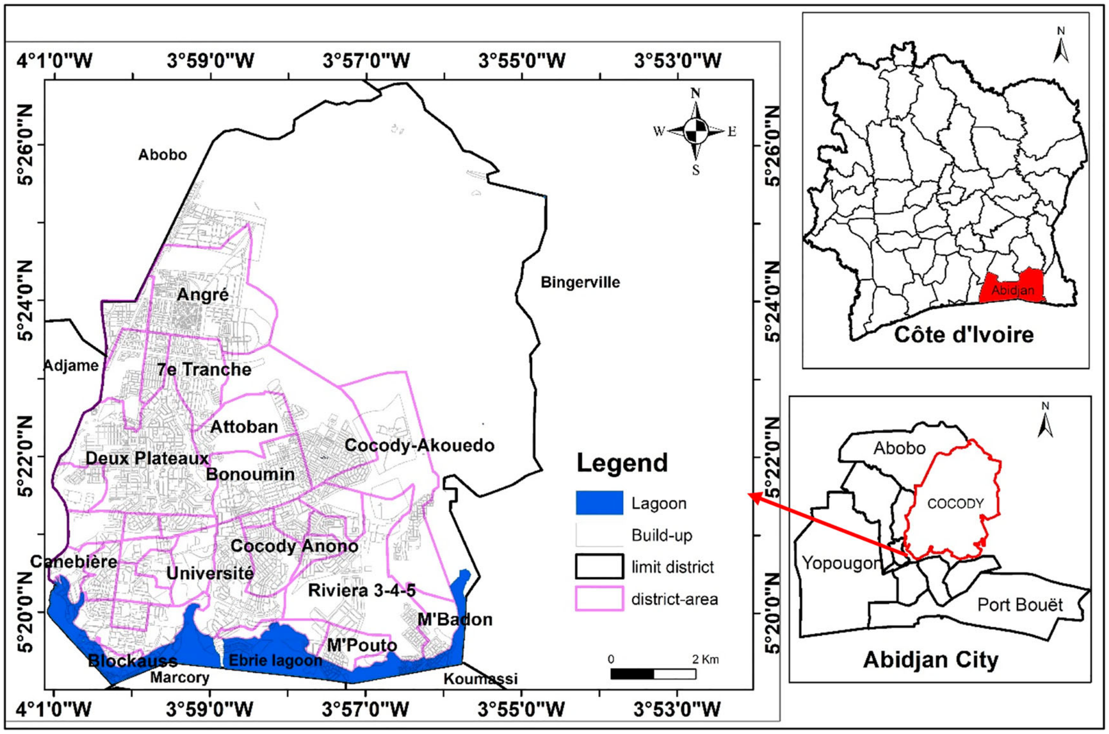


Figure 1. Localisation of the district of Cocody.

projecting them in the geographic coordinate system, using the following path: Universal Transverse Mercator (UTM), World Geodesic System 1984 and zone 30 North Hemisphere. A combination of three bands 4, 3 and 2 (for TM and ETM+) and a combination of bands 5, 4 and 3 (for OLI image) corresponding respectively the red, green and blue bands, were used to enhance the image.

The characterization of urban space was done by conducting the land use/cover classification by differentiating the region of interest (ROI). In this study, a supervised classification, which consists of allocating cases on the basis of their similarity to a set of predefined classes that have been characterized spectrally (Foody, 2002), was employed to categorize the regions of interest into built-up, grassland, forest and water body. In total, 36 training areas were used for each image classification. Image classification consisted of 5 training areas to differentiate the forest, while 10, 9 and 12 training areas helped to differentiate each satellite image into grassland, water and built-up, respectively. Image classification was evaluated based on land use/cover maps of the years 1989, 2000 and 2014 used as “ground truth”. These maps were provided by the Cartography and Remote Sensing Center of Cote d’Ivoire (CCT). Stratified random sampling was used to select the sample cases. Following this method, a minimum number of observations are placed in each category. According to Hay (1979), the size of the samples should be representative and meaningful for an accuracy assessment. Consequently, 40 reference points, derived from these maps, were allocated to each specific class through the district, resulting in a total of 160 reference points for the 4 classes. It helped comparing a sample of locations on the classified map with the same locations on the “ground truth” map. Error matrixes resulted from this comparison. The overall accuracy of image classification was obtained by dividing the sum of corrected prediction to the total prediction (160 in our case). An accuracy of 85% was considered acceptable for classification. A Kappa coefficient (K) was derived using the following equation:

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})}, \qquad (1)$$

where N is the total prediction, X_{ii} is the corrected prediction; x_{i+} corresponds to the ground truth and x_{+1} refers to the total reference point of a class.

After assessing the accuracy of each classified image, change detection analysis was carried out by simply comparing the surface of each class over the years using Excel. Percentage of loss and gain from 1989 to 2014 for each class was calculated.

2.3. *Vulnerability indicators selection and development*

The method presented in this study purports to assess vulnerability using the guidelines of the MOVE (Method for the Improvement of Vulnerability Assessment in Europe) framework as a reference for indicator selection. Based on the MOVE framework, an extensive literature review was initially undertaken. We developed a comprehensive search strategy to first identify articles available in the Google Scholar database with no restriction on the date of article publication. References were to include various aspects of vulnerability to natural hazards (vulnerability analysis, conceptual frameworks, indicators used and weighting methods) in tropical African cities including Abidjan. That helped to identify a potential list of indicators (Table 1).

These indicators were thereafter sent by mail to national and international experts (specialized in vulnerability assessment) for their appreciation and cross-validation. A total of eight experts (five nationals and three internationals) were selected. The selection of these experts was based on their recognized expertise and/or their relevant articles published on vulnerability and natural hazards. The final list of indicators used after experts assessment was based on data availability. This list of indicators was used to characterize the three components of vulnerability (i.e. exposure, susceptibility and lack of resilience).

Elaborated in the context of natural hazard research and climate change, the MOVE framework and its principles have been well described elsewhere (Birkmann et al., 2013). In this study, the MOVE framework key factors are defined as follows:

- Exposure (E). It describes the extent to which a unit of assessment falls within the geographical range of a hazard event (Birkmann et al., 2013). It was measured as the number of people per Cocody district areas, differently exposed to heat condition due to lack or presence of green space. Exposure is calculated by multiplying the density of the population per district area (E1) with the normalized surface temperature per district area (E2). Population data were obtained through the National Standard Bureau (INS), while temperature data derived from the thermal infrared Landsat satellite band, image 2014. The image was acquired on 12 April 2014 at 10 am This thermal image used was the most free of clouds. The time of 10 am was considered to take into account the mean of temperature distribution a day. Indeed, the temperature starts with a low value at 6 am to reach a high value at 2 pm
- Susceptibility (S) describes the predisposition of elements at risk (social and ecological) to suffer harm (Birkmann et al., 2013). The age and health conditions of the population, followed by socio-economic and socio-cultural factors, are the main drivers that shape susceptibility to heat waves (Depietri, Welle, & Renaud, 2013). The same indicators have been used in responding to extreme heat conditions, such as the percentage of unemployed (S1) per district area, and the percentage of age group of inhabitants per district area. This information was taken from the available data which was the INS projection for 2014. The age group addresses the percentage of elderly people (above 65 years) (S2) and the percentage of children under 5 years (S3). A study in the USA (CDC, 2013) found that those people are the most vulnerable because they do not adjust to the sudden change in temperature and mostly rely on other people to keep them cool, especially young children and infants.
- Lack of resilience (LoR) describes the limitations in access to and mobilization of resources of the socio-ecological system and its incapacity to respond by absorbing the impact (Depietri et al., 2013). People respond to heat and stress by changing their behaviour through seeking a cold environment. Hence, lack of green space renders populations more vulnerable to high temperature. It seems, therefore, that the presence of a green space (Gs) is a proxy for the lack of coping capacity. The composite indicator for LoR is then computed by considering the percentage of surface covered by green space per district area.

Before developing an integrated composite indicator for each component of vulnerability, the indictors set were firstly normalized using the Min–Max method in order to have values that are free from units and that lie in a range between 0 and 1. However, because normalization follows certain rules, it is important to assess the functional relationship between the indicator and the vulnerability (Lyengar & Sudarshan, 1982). Thus, when the indicator X_j increases the vulnerability (V), the normalized indicator is computed using the following formula:

$$X_j = \frac{x_j - \min(x_j)}{\mathrm{Max}(x_j) - \min(x_j)}, \quad (2)$$

when the indicators are related negatively to the vulnerability, the normalized value of the indicator is computed as follows:

$$X_j = \frac{\mathrm{Max}(x_j) - x_j}{\mathrm{Max}(x_j) - \min(x_j)}, \quad (3)$$

where X_j is the normalized value of the indicator j of a vulnerability component (E, S and LoR); x_j is the value of the indicator j; Max (x_j) and Min (x_j) are respectively the maximum and minimum values of the indicators j of the vulnerability component. Table 2 presents the functional relationship between the indicators and the vulnerability.

Secondly, we affected weights to the individual indicators by adopting an unequal weighting method, which

Table 1. Preliminary list vulnerability indicators to heat.

Component	Indicators	Justification of the choice	References
Exposure	Population density	The higher the population the higher the number of exposed people	Depietri et al., 2013
	Albedo	Higher albedo surfaces lower air temperature, thus the lower the albedo of an area, the higher the exposure to heat.	Erell, Pearlmutter, Boneh, & Kutiel, 2014
	Spatial variation of temperature	Temperature varies spatially	Depietri et al., 2013
Susceptibility	Percentage of unemployed inhabitants	Jobless people have difficulties to recover from heat effects	Depietri et al., 2013; Nasiri & Shahmohammadi-Kalalagh, 2013
	Percentage of children under four years	Fragile health	Kenneth et al., 2011
	Percentage of elderly above 65	Fragile health	Kenneth et al., 2011
Lack of Resilience	Percentage of green spaces per district area.	Denser vegetation cover increases people resilience to heat	Depietri et al., 2013
	House type	More spaces and aerated houses increase people resilience to heat.	Müller, Reiter, & Weiland, 2011

is a statistical method proposed by Lyengar and Sudarshan (1982). The choice of the weights in this manner would ensure that large variation in one of the indicator would not unduly dominate the contribution of the rest of the indicators and distort inter-zone comparison (Kumar et al., 2014) According to those authors, weights are assumed to vary inversely with the variance over the region in the respective indicators of vulnerability. This gives, therefore, the following formula:

$$W_j = \frac{k}{\sqrt{\text{var}\,(y_j)}}, \tag{4}$$

where k is the normalized constant such as:

$$k = \left[\sum_{j=1}^{n} \frac{1}{\sqrt{\text{var}\,(y_j)}}\right]^{-1}. \tag{5}$$

The normalized indicators were aggregating using the following equation, according to their respective domains (E, S and LoR):

$$(\text{E; S; LoR}) = \frac{\sum_{j=1}^{k} W_j X_j}{n}, \tag{6}$$

with (E, S and LoR) referring to the three components of vulnerability, n being the number of indicators per component, W_j is the weight of the indicator j and X_j is the normalized value of the indicator j.

Finally, we aggregated the three components (E, S and LoR) into the final composite indicator of social vulnerability using the equation below, while taking into account specific weights for the three components of vulnerability as detailed below

$$V = \frac{\sum_{i=1}^{n} W_{ij} X_{ij}}{m}, \tag{7}$$

where V refers to the vulnerability index of a given neighbourhood, m equals the number of components, W_{ij} represents the weights for indicator j of the district area i and X_{ij} is the normalized value of indicator j of the district area i of the components (E, S and LoR). Thus, a weight of 0.33 (two indicators divided by six total indicators) was assigned to the component E, while a weight of 0.5 and 0.17 correspond to the S component (three indicators divided by the six total indicators) and the LoR component (one indicator divided by the six total indicators), respectively. This was done to achieve a balanced structure among the three components within the composite vulnerability index (Hagenlocher, Delmelle, Casas, & Kienberger, 2013).

For classification purposes, a simple ranking of the districts would have been enough. However, for a meaningful characterization of the different stages of sustainability, suitable fractal classification from an assumed distribution is needed. Therefore, the quantile method, which is a predefined function of the ArcGIS 10.1 software, was used for the purpose. To ease interpretation as in Hagenlocher et al. (2013) study, the modelling results were normalized within the 0 to 1 range. The values obtained were grouped into five classes: very low, low, medium, high and very high (Depietri et al., 2013).

Table 2. Functional relationship of vulnerability to warm weather condition.

Components	No	Indicators	Functional relationship
Exposure (E)	1	Population per district area	+
	2	Spatial variation of temperature	+
Susceptibility (S)	1	Percentage of unemployed inhabitants	+
	2	Percentage of children under four years	+
	3	Percentage of people older than 65 years	+
Lack of resilience (LoR)	1	Percentage of green space surface per district area	–

Note: ("+" = Increase vulnerability, "–" = Decrease vulnerability).

The summary of the methodology used for assessing the social vulnerability of Cocody residents to extreme heat condition is schematically shown in Figure 2.

3. Results

3.1. *Urbanization dynamics during the 1989-2014 period*

The results obtained from the process of the satellite images of the years 1989, 2000 and 2014 are shown in Figure 3. During the year 1989, the size of the green environment was greater than the size of the area covered with concrete with sparse forests distributed in the north and north-east of Cocody district. In 2000, just 11 years after the year 1989, a significant decreased size of the forest and an increasing size of the area covered with buildings occurred, which covers approximately half of the total size of the district. The statistical details of the changes that occurred during the periods 1989–2000, 2000–2014 and 1989–2014 are shown in Table 3. It summarizes the statistic on the total lost and gain of the classes from 1989 to 2014. In 1989, the size of the built-up was 30.1 km^2, but the built-up area reaches 67.51 km^2 in 2014. This corresponds to a growth in built-up area by 37.41 km^2. This growth corresponds to 124.29% growth of the built-up class. It is, therefore, the only class that records a growth. The forest lost 11.33 km^2 (98.26%) of its total size.

The same picture is seen for the water and grassland which lost 0.51 and 25.57 km^2, respectively. It corresponds to a decreased in size by 98.79%, 21.4% and 99.79%. The different confusion matrixes as derived from the processing of the satellite images are presented in Tables 4, 5 and 6. The overall accuracy for each processed image was above 85%.

The error matrix shows that there are areas omitted from the correct class categories, and committed to the incorrect classes from the classification of the Landsat satellite images TM 1989, ETM+ 2000 and OLI 2014. In Table 3, the error matrix of the Landsat TM (1989) image classification shows that three areas are omitted from the correct forest category and committed to the incorrect grassland category. The same situation has been observed for water category with one area omitted and committed

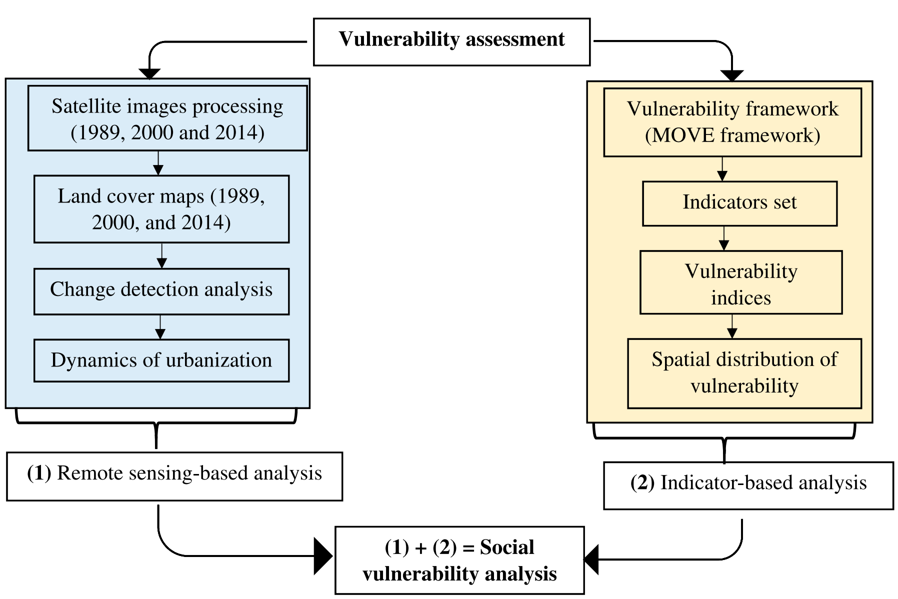
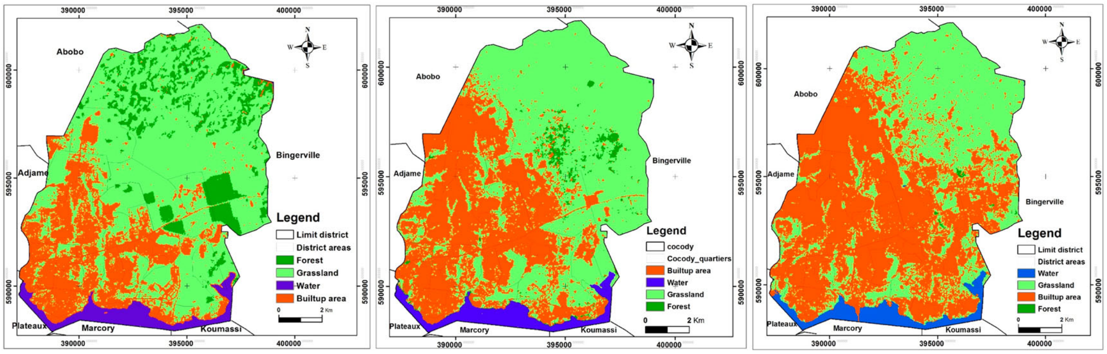


Figure 2. Schematic presentation of the methodology used in assessing the vulnerability.



a. Year 1989 b. Year 2000 c. Year 2014

Figure 3. Land use/cover of the district of Cocody for the years 1989, 2000 and 2014.

Table 3. Land use/cover change detection statistic report of Cocody district from 1989 to 2014.

	Built-up	Forest	Water	Grassland
Initial size 1989 (km^2)	30.1	11.53	5.94	75.07
Final size 2014 (km^2)	67.51	0.2	5.43	49.50
Image difference (km^2)	37.41 (124.29%)	−11.33 (−98.26%)	−0.51 (−8.59%)	−25.57 (−34.06%)

Table 4. Error matrix and classification accuracy of the Landsat TM (1989) image classification.

	Class	Reference point 1	Reference point 2	Control point 3	Control point 4	Ground truth	Overall accuracy	Kappa coefficient
Classified images	Forest	**37**	0	0	0	37	**0.975**	**0.967**
	Grassland	3	**40**	0	0	43		
	Water	0	0	**39**	0	39		
	Built-up	0	0	1	**40**	41		
	Total	40	40	40	40	160		

Table 5. Error matrix and classification accuracy of the Landsat ETM+ (2000) image classification.

	Class	Control point 1	Control point 2	Control point 3	Control point 4	Ground truth	Overall accuracy	Kappa coefficient
Classified images	Built-up	**38**	0	1	1	40	**0.913**	**0.883**
	Water	0	**40**	0	0	40		
	Grassland	2	0	**36**	7	45		
	Forest	0	0	3	**32**	35		
	Total	40	40	40	40	160		

Table 6. Error matrix and classification accuracy of the Landsat OLI (2014) image classification.

	Class	Control point 1	Control point 2	Control point 3	Control point 4	Ground truth	Overall accuracy	Kappa coefficient
Classified images	Built-up	**39**	0	1	2	42	**0.9**	**0.867**
	Water	0	**40**	0	0	40		
	Grassland	1	0	**35**	8	44		
	Forest	0	0	4	**30**	35		
	Total	40	40	40	40	160		

to built-up. In the error matrix of Table 4 for the classified image 2000, there are two areas that were classified as built-up when the reference points indicate that there are actually grassland and forest. Two areas and seven areas were pointed out as grassland while the reference points identify them as built-up and forest, respectively.

3.2. *Spatial distribution of green spaces in Cocody*

The Cocody district lacks green spaces in many areas, specifically Attoban, M'pouto, M'badon, Akouedo, Blokauss, Val Doyen, Plateau Dokui and Cannebiere (Figure 4). Thus, many people do not have these natural spaces in their living environment. These public green spaces are not well spatially distributed across the district as they are more concentrated in the early localities created in Cocody and scarce in the new areas created in the district. The concentration of green spaces per district area was found to decrease with the urbanization process.

3.3. *Cocody residents' spatial vulnerability to heat*

The spatial distribution of urban heat island effect is presented in Figure 5. It shows that the UHI effect is higher in the north-west and in the centre of the district of Cocody, where building density is also higher. The lowest UHI effects were observed in the south and south-east of the district. The number of high exposure areas within the district of Cocody if hazard occurs, based on the density of the population is highlighted in Figure 6 (a). Exposure is sparsely distributed and often in isolated district areas, all around the city centre. The areas most exposed to extreme heat conditions are Deux Plateaux, Akouédo, Cocody Centre, Cité des Arts, Anono and Riviéra Sogéfiha. The most susceptible areas are concentrated in the southern part, particularly in the south-east comprising Riviera 3-4-5, Riviera-Golf 2 and M'pouto, and the middle and western part of the district including Danga, Université and Cité des Cadres (Figure 6(b)). The lack of resilience is very high in three specific geographical areas of the district: the south-east (M'badon, Rivieara 3-4-5 and M'pouto), the south-west (Val Doyen and Ambassade) and the north with Angré and Plateau Dokui (Figure 6(c)).

The result of the combination of the three composite indicators of the three components of vulnerability is summarized, mapped and displayed in Figure 7. It spatially shows the vulnerability of the Cocody areas to extreme

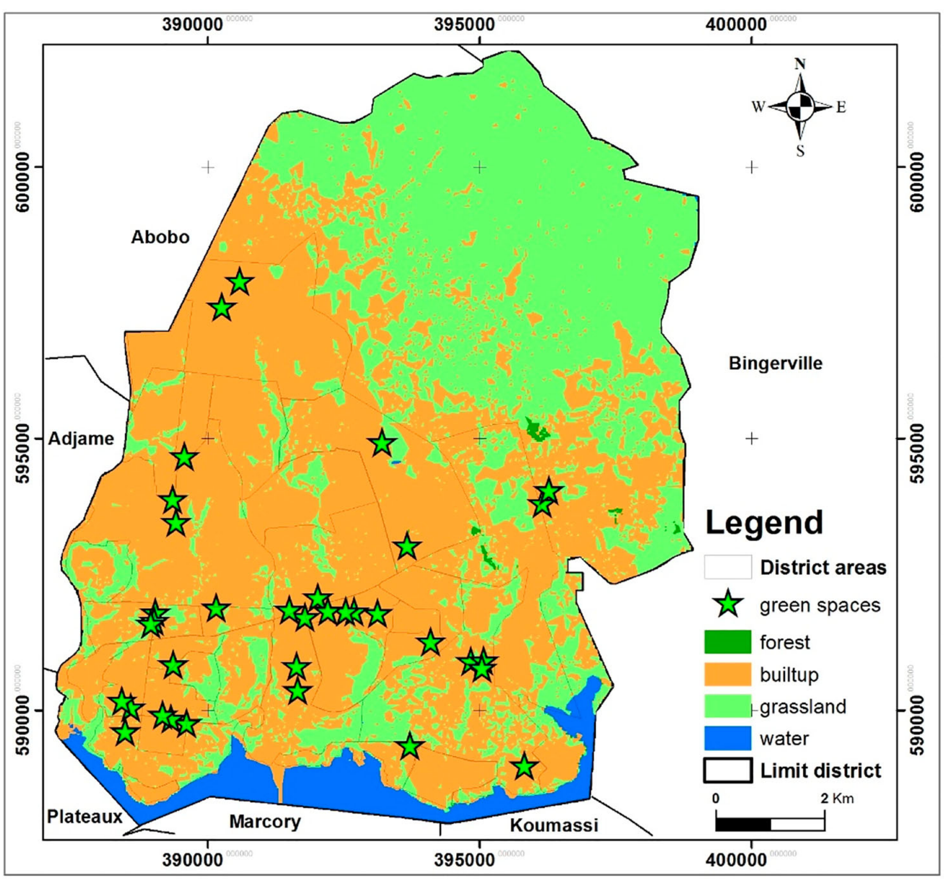


Figure 4. Spatial distribution of green spaces in Cocody.

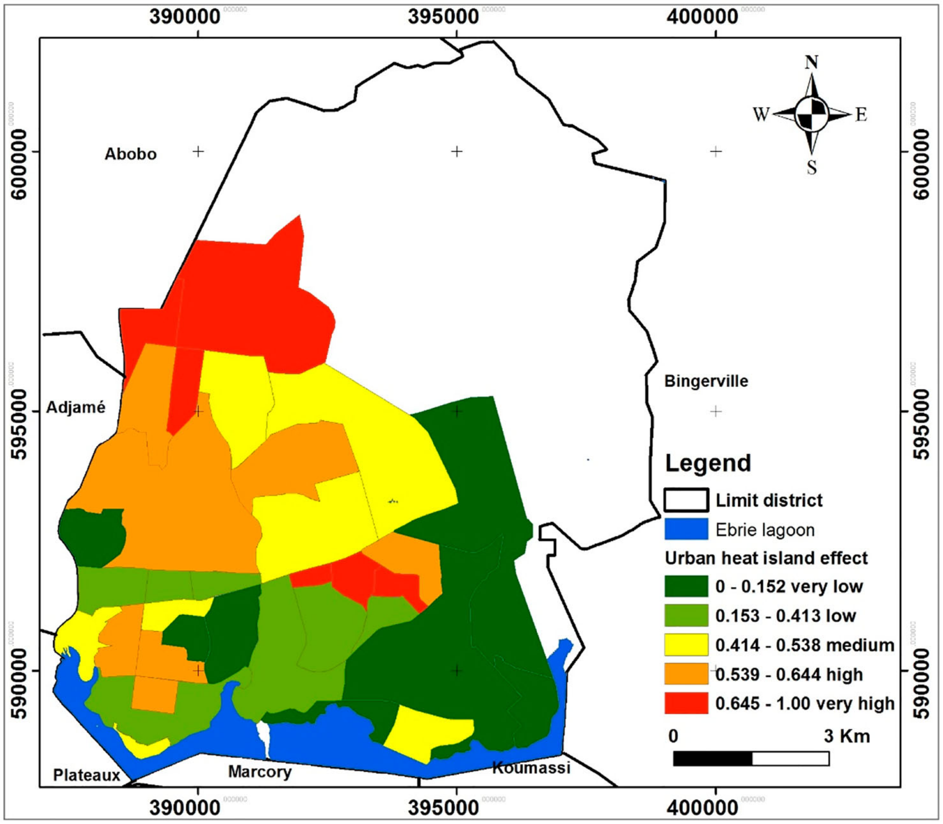


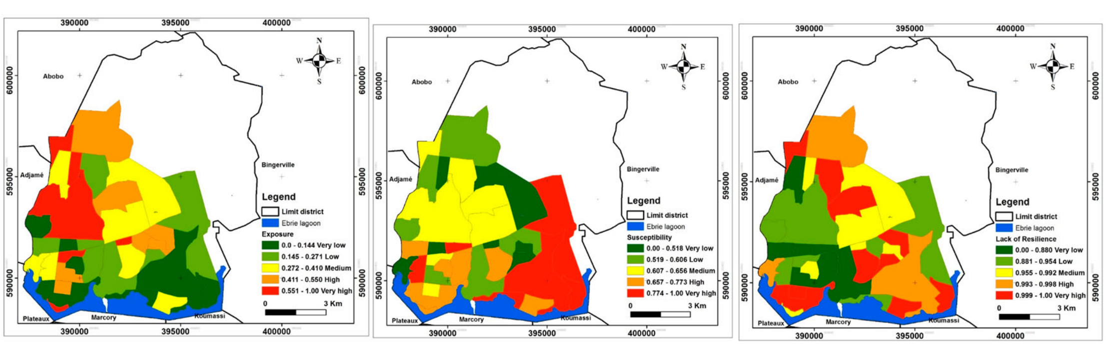
Figure 5. Urban heat island effect based on Landsat thermal band (obtained on 14 April 2014).

heat events which may extent to hazard. The highest vulnerable Cocody areas to extreme heat condition were found to be M'badon, Akouedo, Deux Plateaux, Danga, Cité des Arts, Riviera-Golf 2 and Blokauss. They represent 18% of built areas of the district while the lowest vulnerable areas (Canebiere, Ecole Gendarmerie, Sideci-zoo, Universite Riviera-Golf 2, Riviera EECI and Copraci-Coprim) represent 7%.

In sum, Cocody is undergoing fast urbanization with great loss of natural environment. Many district areas lack considerable adequate green spaces, rending inhabitants more vulnerable to extreme heat conditions. This risk incurred by the population is further increased by demographic changes leading to more susceptible groups living in the area.

4. Discussion

The use of supervised classification as a method for satellite image processing allowed differentiating four land use/cover classes, namely built-up, forest, grassland and water. The overall accuracy values showed that all the



a. Exposure of Cocody inhabitants to heat conditions b. Susceptibility of Cocody inhabitants to heat conditions c. Lack of resilience of Cocody inhabitants to heat conditions

Figure 6. Exposure, susceptibility and lack of resilience of Cocody inhabitants to heat conditions.

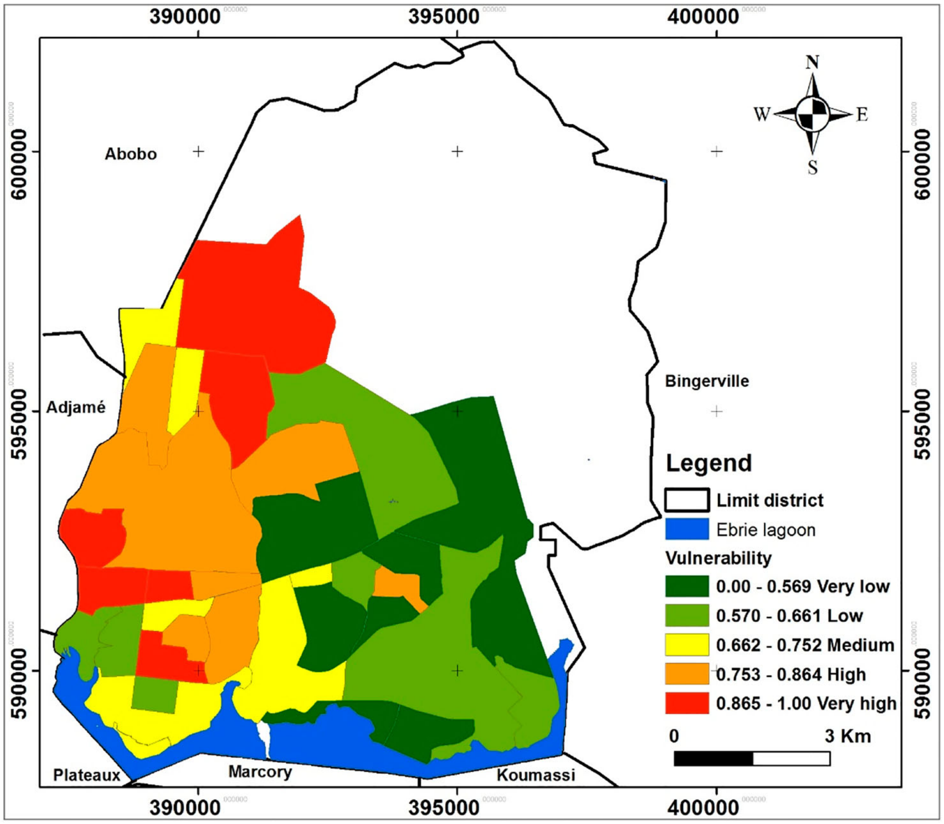


Figure 7. Vulnerability of Cocody inhabitants to heat conditions.

maps were well classified and exceeded the minimum accuracy of 85% required (Foody, 2002). Moreover, the classification assessment delivered good results for the kappa coefficient. These high values might be due to the small number of class categories chosen for urban classification. Thus, according to Congalton and Green (2008), the accuracy of a map depends on the variability of the categories to be mapped. However, though the classification assessment showed good results of the classification, the reference points used as ground truth and the absence of actual ground-observed ground data may have led to a distortion of error matrix and accuracy statement as highlighted by Foody (2002). The landscape dynamics analysis and the change detection statistic method employed in this study revealed that urbanization accounts for the loss of the natural environment. From 1989 to 2014, the built-up grew by 124.29%, while the forest, the grassland and the water decreased by 98.26%, 34.06% and 8.59%, respectively, indicating that the natural environment is substituted by the built-up. This progressive loss of the natural environment seems to be proceeded by the disappearance of vegetation (forest and grassland) replaced by the built-up in progress in the south and south-east of the district of Cocody in 2014. The rapid urbanization witnessed by Cocody is based on rapid growth of population leading to a massive demand of land for house. In fact, Cocody is one of the wealthiest and most secured districts of Abidjan with availability of unsealed land, which explains the high demand for expanding property in this district. However, Cocody is not the only district of Africa that witnesses the fast growth of built-up disregarding the natural environment. Mensah (2014) noticed that urban green spaces are been depleted at an alarming rate in several urban areas in Africa and occupy now small and smaller land masses. Although urbanization contributes to the intense loss of natural environment, it appears not to be the only cause. According to Driscoll and Starik (2004), the loss of natural environment may also be explained by the greening policy of stakeholders. Study outcomes suggest that green environments are not the priority for the city authorities. Instead, they prefer to accommodate more people, create more schools and markets in the public areas previously reserved for garden and green spaces. Although the green environment is disappearing due to the urbanization process, it could be restored by greening policies. A study in China (Zhou & Wang, 2011) recognized that both rapid urbanization and greening policies accounted for the process of green space change; however, greening policies have helped for the recovering of grass lands in the last decade.

Green spaces are sparsely distributed in Cocody. The analysis of its spatial distribution lets one to conclude that Cocody lacks adequate green spaces in the living environment of the population for their well-being. Nassa (2008) noticed the same in their research in which they highlighted the substitution of green spaces by built-up. Many people might, therefore, be far from green environments. This distance is used often by the population who are deprived of the many benefits of green spaces in urban area: health benefits (stress and mental health reduction, improved concentration), physical benefits (enhanced health, improved environmental condition) and social benefits (crime reduction, positive effects on children) (Lee & Maheswaran, 2011; Jones, 2009). This confirms the theory about the carelessness of city's stakeholders vis-à-vis green space and socio-ecological property for a good living environment.

The social assessment of the vulnerability of Cocody's inhabitants to extreme heat condition was based on the MOVE framework, and integrated both quantitative and qualitative data analysis. From the quantitative view, the district of Cocody is highly populated which exposes more inhabitants to extreme heat conditions. Nevertheless, the exposure of Cocody to warm days is expected to be lower, compared to other districts of Abidjan based on population density (PUIUR, 2011). Yet, particular attention should be given to this district as the vulnerability was more correlated to the density of population than spatial variation of temperature. Table 7, performed with "SPSS Statistics" by computing a correlation and significance test (2-tailed at 5%), presents the weight of each vulnerability components on the model output. Thus, all the components (E, S and LoR) were found to be significantly correlated to the vulnerability at different levels.

The correlation between vulnerability and its components such exposure, susceptibility and lack of resilience, is highly significant at 1% (p-value = .001 for exposure, .000 for susceptibility and .006 for lack of resilience). Regarding vulnerability and indicators, correlation is highly significant at 1% with the density of population (p-value = .001), with children under five years of age (p-value = .009), unemployment (p-value = .004) and green spaces (p-value = .006). Therefore, susceptibility and lack of resilience have the highest impacts on the model output. As the areas of highest vulnerability (18%) are more important than the lowest vulnerability areas (7%), this suggests that Cocody is more vulnerable to heat. The thermal band allowed to better appreciate the spatial distribution of temperature during the day. Since the snapshot of the thermal image was taken at the same period as the other indicators, this has facilitated better integration and analysis.

Overall, vulnerability was observed to be higher in the south-eastern and western part of the district, where most of the vulnerable people (children) were recorded. Moreover, most of these more susceptible areas lack considerable and adequate urban green spaces which could help inhabitants to reduce the vulnerability of more fragile groups. According to "Natural England", contact with natural environment helps create strong and healthy communities with more active and less stress individuals (Sallis et al., 2006). This was confirmed by De Vries (2001) whose study concluded that for every 10% increase in green space there is a reduction in health complaints equivalent to five years of human life span. Green spaces are also known for their beneficial effects on human health and as a shelter against the harmful effects of heat and for reducing urban heat island effects (Berg, Maas, Verheij, & Peter, 2010). Benefits given by the existence of green spaces in urban areas include social inclusion that facilitate contact between people of all ages both informally and through participation in social and cultural events, reduction of urban stress and mitigation of the impression of rigidity and aridity of buildings. Thus, apart from the visible impacts (heat-related illness) on people, insecurity posed by extreme heat violates some of the most basic principles of human right, as mentioned in the first principal of the 1972 Declaration of the UN conference on the environment held in Stockholm. Therefore, equally distributed adequate green space within a given area where population are susceptible and exposed groups to heat can be a way of reducing the social injustice and promoting human security. Moreover, green space can

Table 7. Correlation of components with vulnerability.

E1	1									
E2	.025*	1								
E	.000**	.000**	1							
S1	.754	.086	.410	1						
S2	.374	.277	.233	.746	1					
S3	.727	.458	.815	.093	.446	1				
S	.909	.064	.243	.000**	.001**	.000**	1			
LoR1	.675	.543	.536	.444	.938	.478	.991	1		
LoR	.675	.543	.536	.444	.938	.478	.991	.000**	1	
V	.001**	.049	.001**	.009**	.110	.004**	.000**	.006**	.006**	1
	E1	E2	E	S1	S2	S3	S	LoR1	LoR	V

Note: Pearson correlation (**$p < .01$ and *$p < .05$).

be a tool for disaster risk reduction, representing a safe venue for emergency services such as the provision of relief supplies as well as for setting up a security command centre and medical aid stations (Liu et al., 2013). From the qualitative point of view by field observations, the vulnerability of the inhabitant of Cocody's, as shown in the spatial quantitative analysis seems different from what the quantitative outcomes suggest. Although Deux Plateaux appears to be highly vulnerable to extreme heat conditions, the field observations suggest the opposite. Deux Plateaux is one of the wealthiest areas, with trees along the roads and high rise houses, offering more space to the inhabitants and generating a cooler environment. Moreover, as the vulnerability is highly correlated with the lack of resilience (green spaces), vulnerability in Deux Plateaux should normally be low. According to Tanaka, Takano, & Nakamura, 1996, senior citizens live longer when more space is available and with nearby parks and tree-lined streets near to where they live. The same observation is valid for Palmeraie, where the vulnerability appears low; however, it lacks considerable vegetation cover. The vulnerability of an area is, therefore, a combination of both socio-economic and environmental factors rather than only environmental factors (Okayo et al., 2015; Mendel, 2006). Moreover, some features such as type of house, vegetation cover and spatial variation of surface temperature were not taken into account when computing the vulnerability index. Nevertheless, the quantitative data gathered provided insight into indicators of vulnerability that should be considered when designing a city.

The MOVE framework adopted in this study facilitated the use and the combination of several local indicators, which constituted a real advantage. It helped reduce the complexity of vulnerability to a single index value, which allows grasping the current situation at one glance. Thus, it can be used for communication and serve as the first basis for decision-making. It can help tell where people are most exposed to heat and where the most vulnerable people are. That can facilitate timely response strategies during a hazard by pointing towards areas that should be prioritized. As the approach can be transferred, e.g. to other regions of the city, it can be used as a decision-making tool that helps risk managers and land-use planners to develop and plan measures for vulnerability reduction. However, some challenges have to be highlighted. The modelling approach is not spatially explicit as it builds on indicators which were reported at sub-district level (Hagenlocher et al., 2013), neglecting the heterogeneous and continuous vulnerability within a sub-district and across all sub-districts of the district. That results in artificial boundaries that bring out social problems by considering a sub-district as a closed block with no interaction with other sub-district. Thus, providing for more realistic vulnerability mapping spatially explicit modelling approaches are needed, which enable continuous and heterogeneous vulnerability estimation within and among sub-districts.

The weighting method used presents some advantages but also some limitations. The weight does not depend on ad hoc restrictions; however, reliability and robustness of the results depend on the availability of enough data. Moreover, the weight given to each indicator is based on purely statistical validation and does not reflect any external stakeholders' views. As stakeholders are the end-users, their appreciation would have given more value to the weight.

5. Conclusion

The district of Cocody is one of the wealthiest districts of Abidjan. During a period of 25 years, it witnessed a fast urbanization process represented by 124.29% growth of areas designated as built up. As consequence, areas of natural environment where lost including 98.26% of forest areas, 34.06% of grassland and 8.59% of water. Meanwhile, the policy encouraging the disappearance of the natural environment seems to neglect the harmful effects of heat and increase in hot days. The vulnerability map has shown numerous district areas lacking considerable green spaces, exposing more Cocody residents to extreme heat conditions. Actions should, therefore, be taken to alleviate vulnerable inhabitants from extreme weather conditions and promote human security. The results of our vulnerability assessment suggest that to effectively tackle the vulnerability of Cocody district to extreme heat conditions, collaboration among local city authorities in charge of urban planning and environmental management is needed to implement strategies which will improve the socio-environmental conditions of the city for the well-being of the residents. The main greening strategies should consider the spatial distribution of susceptible groups across the district. A more active use of population demographics and background characteristics for district planning could be helpful when planning and managing green space in urban areas. The result further indicates that green spaces, density and age class are important factors that need to be taken into account for tackling vulnerability to heat. City planners should, therefore, take the distance to green space into consideration, especially for new residential areas, areas with many residents, and areas where distance is more likely to be a limiting factor. Also, private vegetation planting at the household level should be encouraged.

The outcomes of this study need to be reinforced with other studies taking into account more and more accurate data such as the updated population size. A future vulnerability assessment of the district should take into account the characteristics of buildings and trees settings along main roads as they may impact in the well-being of the residents. Moreover, stakeholders should be involved for allocating selecting and allocating weight as they are the end-users.

Disclosure statement

No potential conflict of interest was reported by the authors.

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