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Land use change and urban heat islands in the seaside town of Kribi (Cameroon): Vulnerability and adaptation strategies

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Abstract

Urban heat islands (UHIs) are a pervasive manifestation of climate change in cities worldwide. In African coastal cities, often situated in low-lying areas with stagnant air, rapid demographic growth, and irreversible land-use changes, the proliferation of heat islands poses significant risks to vulnerable urban populationsa. This study investigates the interplay between land-use changes, the rise of heat islands, and the vulnerability of city dwellers in the seaside and port city of Kribi, Cameroon. It also explores effective adaptation strategies to mitigate the impacts of heat islands. Google Earth (GE) imagery from 2015, 2019, and 2023 is employed to assess land-use dynamics. Surface temperatures are analyzed for 2015, 2017, 2019, and 2023 using Landsat 8&9 imagery and Qgis 2.18 software. Meteoblue meteorological data is used to validate the findings. A GPS survey of air conditioners in Kribi, conducted using the SWMap mobile application, provides insights into stakeholder involvement and air conditioner categories. Additionally, a questionnaire administered to 200 city dwellers gathers information on their vulnerability to heat islands and mitigation strategies. Currently, surface temperatures in Kribi are projected to range between 26°C and 35°C between 2015 and 2023, with significant spatial variations in heat islands. To cope with these rising temperatures, most building occupants rely on air conditioning. Over 41% of surveyed city dwellers use air conditioning in their homes, with the highest proportion found in hotel and catering facilities (52%), followed by service offices (16%) and private homes (14%). Green space in Kribi has drastically declined between 2015 and 2023. In 2015, green space constituted 5,169 ha (83%), but by 2023, it had shrunk to 2,516 ha (43%), a loss of 261 ha. This decline was consistent between 2015 and 2019, with green space falling from 4,908 ha (83%) to 2,516 ha (43%).

Keywords: Land-use change; heat islands; vulnerability; air conditioning; Kribi seaside town, Cameroon

I. Introduction

Urban surface temperatures are expressed in terms of urban heat islands (UHIs), also known as "urban heat islands", designating a metropolitan area whose temperature is significantly higher than that of the surrounding "rural" areas. There is therefore a strong contrast between the temperature values in the city and those in the countryside, because the latter still has sufficient natural areas to attenuate solar radiation and reduce surface temperatures (Doutreloup et al., 2022). The countries of the Gulf of Guinea, like many others, are facing the phenomenon of rapid urban growth (Losch & Magrin, (2016), resulting in spectacular urban sprawl that devours the natural environment (Mbaha, & Tchounga, 2020; Essono Milla, 2022), coupled with rapid demographic growth (Tabutin, 1991; Leridon, 2015; Delaunay & Guengant, (2019). The direct consequence of this spatial expansion of the city is the degradation of in situ vegetation cover (Rudel, 2013; Eloy & Le Tourneau, (2009; Petrişor et al., 2020). This degradation leads to an increase in surface temperatures (Wan Mohd et al., 2020) and an increase in UHI. These changes in land use must be curbed in order to limit their impact on the environment.

In order to understand the dynamics of land conversion, space technologies, in particular remote sensing applied to the study of areas undergoing change, are being used, as they have undergone significant development (Rogan & Chen, 2004) and have been the subject of a large body of literature throughout the world in the study of land use change (Green et al., (1994). Wu et al, (2006); Alqurashi and Kumar (2013); Letsoin et al, (2020) have used them to monitor and detect land cover change in their respective studies. Carleer et al, (2005); Grippa et al, (2018) have shown the importance of satellite image segmentation in monitoring and mapping land cover changes in urban areas.

In tropical Africa, Lambin et al (2003) carried out spatial modelling of land use change factors based on satellite images, while assessing the progress of this approach in predicting the location versus the quantity of land use change. Most recently, Akalu et al (2019) applied remote sensing to monitor land use change in a sub-catchment in eastern Ethiopia. In Morocco, Barakat et al. (2019) used remote sensing images to assess the environmental impact of land degradation and land use in the district of Beni-Mellal.

In Cameroon, Fonge et al (2019) and Zekeng et al (2019) studied changes in land use in peri-urban protected areas, focusing on the Barombi Mbo reserve and the Doumé communal forest in coastal and eastern Cameroon respectively. In the Douala-Edéa Faunal Reserve, Kana et al (2019), using a large mass of high (spot 5) and very high spatial resolution (Google Earth) images, carried out a supervised and unsupervised classification to produce a map of forest dynamics in this area of high conservation value around the city of Douala. In the same vein, the Cameroonian consultancy Action for Sustainable Development (Nguénang, 2015), as part of the GEOFORAFRI projects, carried out work on the spatio-temporal dynamics of the Douala-Edéa Faunal Reserve with a view to highlighting pockets of degradation. This study was based on a multi-sensor remote sensing approach, using Landsat images over three periods (Landsat TM, ETM and OLI).

Google Earth (GE) images are even more interesting for understanding land cover and identifying land use patterns (San Emeterio et al., 2021), although they overestimate the facts observed on the ground by 1% and underestimate them by 8.3% (Frankl et al., 2013). They are often used in many studies to validate results, despite the poor quality of their spectral characteristics (consisting solely of red, green and blue (RGB) wavelengths). Hu et al (2013) recommend the use of GE images to solve problems related to land cover. For example, Hamud et al (2021) used GE images to monitor urban expansion and changes in land use in Banadir, Somalia. Zurqani et al (2019) used GE images to analyse the urban grid. Zhao et al. (2021) used GE imagery for the spatial-temporal analysis of land-use changes in the coastal city of Hangzhou Bay in China.

With regard to Cameroonian cities, Duna et al (2021) assessed the spatial dynamics of the city of Yaoundé on the basis of satellite images, using GE images as a validation source. To the south of Douala airport, Bengono Nkodo (2021) used a series of GE and Pleiade images to monitor the Consequences of urbanisation in the mangrove coastal area of the Wouri estuary. In Kribi, studies of changes in land use have already been carried out, but using Landsat images with low spatial resolution (30 m). This is the case of Saha and Tchindjang, (2019) who assessed the spatiotemporal dynamics of the town of Kribi by highlighting the environmental factors and consequences. Mbevo et al (2018) also analysed landscape dynamics between 1984 and 2016. This study already showed the tendency of the city of Kribi to expand into its hinterland.

These changes in land use patterns lead to variations in surface temperatures (Ghilain et al., 2023), which need to be analyzed in order to highlight heat islands. This correlation between changes in land use and surface temperatures has been the subject of several studies around the world. Devendran & Banon, (2022) assessed the spatio-temporal variation of land use changes and their impact on surface temperatures in the city of Accra in Ghana, using Landsat images. Kalma et al (2008) used an estimate of surface evaporation to develop a remote sensing method for measuring surface temperatures and highlighting heat islands. In this way, soil with little cover will tend to heat up more than uncovered soil. Jiménez-Muñoz et al (2014) used the same method, based on Landsat 8 images, to measure surface temperatures. Guha et al (2018) will use the same image sources (L8) to assess surface temperatures in the cities of Florence and Naples, using the normalized vegetation index (NDVI) and the brightness index (NDBI). These two indices play a decisive role in understanding the nature of the interactions between incident solar radiation when it encounters vegetation or buildings/bare ground.

In Cameroon, Nguemhe et al (2018) assessed surface temperatures in the city of Douala using Landsat images. How Jin Aik et al (2020) carried out a study of the relationship between variations in surface temperatures and changes in land use in the agro-ecological zone of the high savannahs of West Cameroon, an environment highly anthropized by agricultural and pastoral activities (Morin, 1994). More recently, Ebodé (2023) has highlighted variations in surface temperatures in relation to changes in land use in the Mefou catchment, in the Central Cameroon region.

In a context marked by climate change, these heat islands are tending to increase both spatially and in terms of how they are felt, making city dwellers more vulnerable, with impacts on their health (Levy, 2016) and on comfort levels inside and outside buildings (Molina et al., (2023). Mena et al (2016) have already highlighted the rise in temperatures in the city of Kribi, which is having a negative impact on the residents of this seaside resort. They are imposing de facto mitigation mechanisms on urban populations. The solution most envisaged by the urban populations of Kribi is the use of air conditioning and fans.

Whether we live in the tropics or not, air conditioning helps to combat rising temperatures, particularly inside houses (Zélem, (2007); Giguère, M. 2009). In the popular perception, air conditioning provides a sense of well-being and sufficiently reduces suffocation in buildings (Drapeau, 2021). It is therefore necessary to cool the inside of houses for greater comfort (Ameglio et al., 2019). The demand for air conditioning is even greater in this context marked by climate change (Gaaloul & de l'Environnement, 2021), where extreme temperatures are felt inside homes. This is undoubtedly what prompted Anquez & Herlem (2011) to look into the causes, impacts and solutions to the rise in heat islands in urban centres. Sentenac, (2016) will simulate scenarios for reducing heat islands by 2050, for the metropolitan community of Montreal, in a context marked by climate change.

This study seeks to establish the correlation between changes in land use, the increase in heat islands, ambient climate change and the vulnerability of city dwellers in the seaside town of Kribi in Cameroon. The results will be discussed in the light of existing literature and on the basis of weather data collected on the NASA and Meteoblue websites for the city of Kribi.

II. Presentation of the Town of Kribi

Kribi, a coastal town nestled in the Gulf of Guinea along Cameroon's shores, lies at the mouth of the Kienké River. Spanning approximately 20,300 hectares, Kribi is administratively situated in the South Region and the Ocean Department, serving as the capital of the Kribi district. The town encompasses two communes: Kribi 1er and Kribi 2ème (Figure 1).

Kribi's climate falls under the humid equatorial type, influenced by the monsoon, a characteristic feature of coastal regions (Suchel, 1988). The town experiences an average annual rainfall of around 2,900 mm. December, January, February, and March constitute the primary dry season, with an average rainfall of 262 mm. Conversely, September, October, and November form the main rainy season, averaging over 1,183 mm of precipitation (Mena et al., 2016).

Temperatures in Kribi remain relatively high, with a diurnal temperature range of 2.42 degrees Celsius. Maximum temperatures typically range from 26°C to 31°C, with peaks often observed during the dry season. Minimum temperatures fluctuate between 23°C and 25°C during the rainy season. Prevailing winds blow from the southwest at approximately 16 km/h, accompanied by humidity levels that can reach 83% depending on the time of day.

Kribi's origins trace back to the colonial era (Bahuchet, 2010), a fact that contributes to its organized spatial and administrative structure. The Batanga, Mabi, and Bagyeli were the town's first inhabitants. Kribi is among Cameroon's cities that witnessed a nearly four-fold population increase between 1976 and 2010, rising from 11,261 to 59,928. A 2022 estimate places the town's population at 200,000. This demographic growth has accompanied Kribi's spatial expansion, particularly since its transformation into a port city following the construction of the Kribi Industrial Port Complex (CIPK) between 2007 and 2018. This development aligns with the Cameroonian government's emergence policy, outlined in the Growth and Employment Strategy Paper and subsequently in the National Development Strategy 2030 (SND 30), spearheaded by the Ministry of Economy, Planning and Regional Development (MINEPAT, 2009 & 2020).

While Kribi possesses an urban development master plan and a land-use plan (CUK, 2013 & 2015), these plans are not being adhered to. The town's strong demographic growth and the in-situ expansion of the urban fabric have led to forest cover degradation, resulting in a rise in surface temperatures.

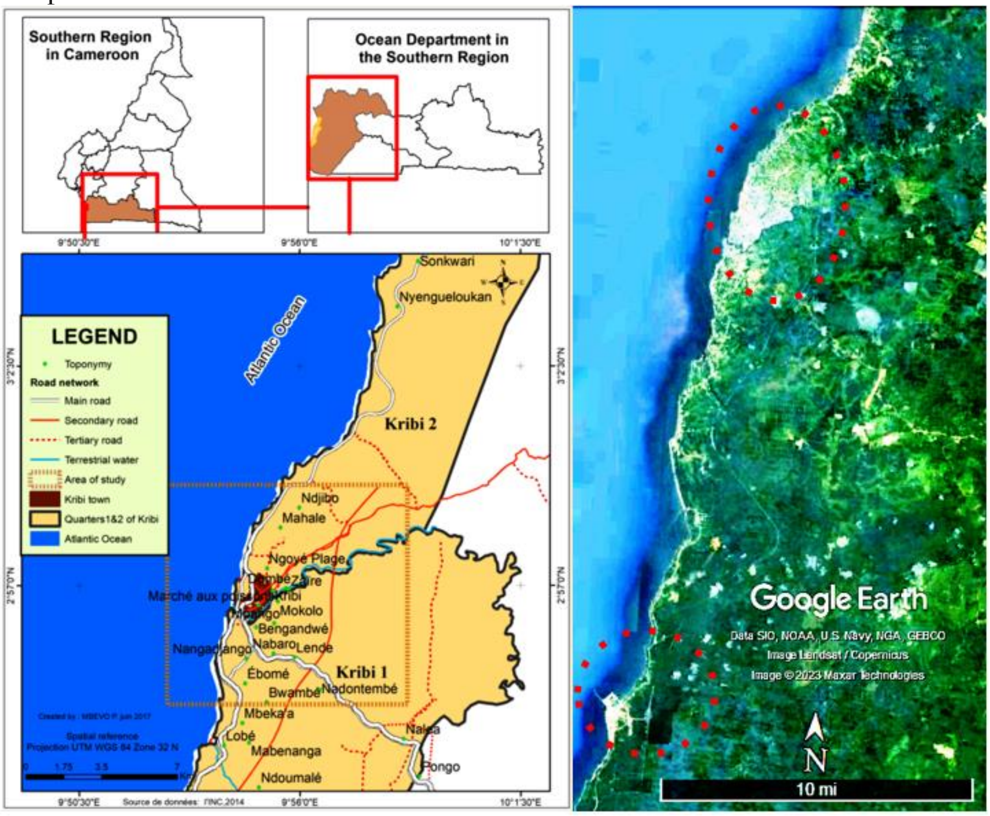

Figure 1: Location map of Kribi on the Coast of Cameroon

III. Tools and Methods

III-1. Assessment of Land-Use Changes in Kribi

The analysis of land-use dynamics was based on Google Earth (GE) Pro images. Google Earth is a mapping portal that provides satellite images of the entire globe, captured by various operators, including NASA and ESA.

These images offer very high resolution (1m) of the earth (Bengono, Nkodo, 2021). We utilized Google Earth images from 2015, 2019, and 2023, which are available for the town of Kribi. These images were exported as .JPG files and underwent geometric (georeferencing) and spectral (classification) processing.

III-1-2. Processing Google Earth Images

III-1-2-1. Image Extraction and Georeferencing

GE Pro software was utilized for this process. After activating the historical images tab, we could view all available images and select those of suitable quality for analysis (free of cloud cover). Each image was then saved in .JPG format and imported into Qgis 2.18® for georeferencing. Georeferencing was accomplished using the "GDAL Georeferencer" extension. This approach requires access to another georeferenced image source of the same spatial resolution, such as a digital terrain model or a Quick Bird image. In this instance, we employed a Quick Bird image of the same spatial resolution.

III-1-2-2. Image Classification

The supervised classification approach was chosen, utilizing Qgis 2.18® software and the Semi-Automatic Classification Plugin (SCP). Developed by Luca Congedo, the SCP plugin facilitates supervised classification of remote sensing images, providing tools for downloading, pre-processing, and post-processing images. It is compatible with ASTER, Landsat, MODIS, and Sentinel2 images, offering a range of algorithms. Installation of GDAL, OGR, Numpy, SciPy, and Matplotlib is required for this plugin. Three land cover classes were defined: buildings, vegetation, and hydrography. The hydrography class was not considered in the surface temperature analyses.

III. Research Methodology

III-1-2-3- Calculating the Annual Rate of Land Use Change and Assessing Vulnerability to Changes in Land Use Classes

The annual rate of change represents the proportion of each land cover class that has transformed over the years (Agbanou et al., 2018). This calculation is based on land cover statistics for the different classes and is determined using the following formula by Puyravaud (2003):

$$TAC = \frac{(\ln(S2 - S1)}{(t_2 - t_1)\ln e} X\,100$$

Where:

- APR: Annual rate of change
- S1 and S2: Area of a landscape unit at date t1 and t2 respectively

- t2-t1: Number of years of evolution
- ln: Neperian logarithm
- e: Basis for the neperian logarithm (e = 2.71828)

The vulnerability to change of each type of land use is calculated using the following ratios (Biaou et al., 2019):
Gain/stability (Gs = g/s)
Loss/Stability (Ps = p/s)
Net change/stability (Ns = Gs-Ps)
The terms g, s, and p represent respectively the gains, areas of stability, and losses of surface area for each land use class during the period observed.

III-2- Modeling Surface Temperatures Using Landsat 8 Images and Highlighting Heat Islands in the City of Kribi between 2015 and 2023

Surface temperatures were modeled using Qgis 2.18® software, via the RS&GIS plugin. This tool runs well-defined algorithms on the raw satellite data to produce outputs such as Land Surface Temperature (LST) in degrees Celsius, Satellite Brightness Temperature, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), etc. (Kamal et al., 2022). For LSTs, the algorithm uses Landsat 8 bands 10 & 11. These are thermal infrared (TIR) bands that have the ability to see the heat on the ground while the image is being taken. Instead of measuring air temperature, as weather stations do, these bands (10 & 11 of L8) instead record ground temperatures, which are often much warmer. These images date from 2015, 2017, 2019, and 2023 and were taken at the same time of day and during the same season (table 1).

Table 1: Characteristics of Landsat satellite images

Data	Season	Pick-up time	Path & Row	Sensors	Spatial resolution	Radiometry	Bands	Purpose
2015-03-25	Dryer	09:32:33	186 058	LC8	100 m	16 bits	10&11	LST
2019-01-30	Dryer	09:33:00	187 057	LC08	100 m	16 bits	10&11	LST
2023-12-21	Dryer	09:33:33	186 057	LC09	100 m	16 bits	10&11	LST

III. Field Survey

III-3-1. Questionnaire Presentation

A randomly administered, individually completed questionnaire was designed and distributed among Kribi city dwellers. It comprised four sections: section 1 focused on respondent identification (6 questions); section 2 addressed land-use changes in Kribi (6 questions); section 3 examined the perception of heat islands in Kribi (8 questions); and section 4 explored vulnerability and mitigation strategies for heat islands in Kribi (14 questions). To be eligible for the survey, respondents had to have resided in Kribi for at least five years. This duration of residency provides a better understanding of surface temperature variations within the city.

III-3-2. Surveyed Neighborhoods

A total of 16 neighborhoods in Kribi were surveyed. Based on the number of respondents (200), the following neighborhoods were included: Wamié (2), Mimbogue (3), Bossigui (4), Quartier résidentiel (4), NZIOU (5), Afan Mabe (7), Bongandoué (8), Dombè Boshigui (8), Ebomé (8), Londji (8), New-Town (10), Mokolo (15), Ngoyé (20), Petit paris (23), ZAÏRE (30), and Grand Batanga (45) (Source: October 2023 field survey).

III-3-3. Gender, Education Level, and Age Group of Respondents

In terms of gender, 140 male respondents completed the questionnaire, compared to 60 female respondents. Regarding educational attainment, 2.5% of respondents had completed primary education only, 29% had secondary education, and 68.5% had tertiary education. Finally, age ranges varied from under 25 to over 65 (Figure 2).

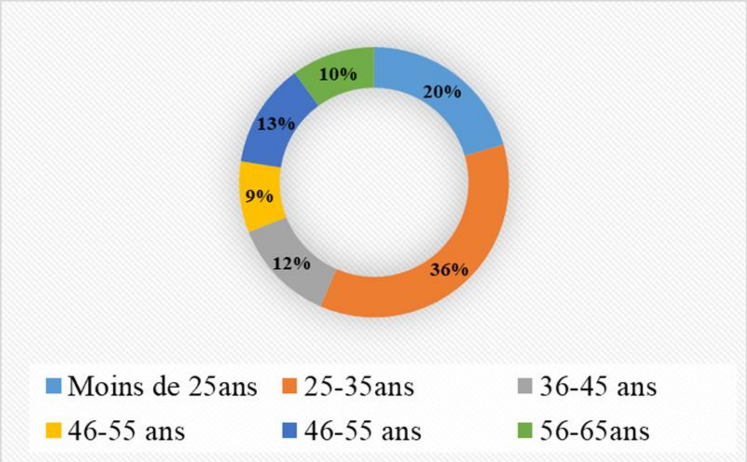

Figure 2: Variation in age groups of respondents in Kribi
Source: October 2023 field survey

III-3-4. Life Expectancy of Respondents in Kribi

The respondents in Kribi are predominantly native residents (Table 2), meaning individuals born and raised in Kribi. This category is followed by individuals who have resided in Kribi for five, 20, and nine years, respectively (Source: October 2023 field survey). The average lifespan of respondents in this town is 13.6 years. This average is well-suited for this study, as it ensures that respondents have a genuine understanding of land-use changes and surface temperature variations in this seaside town.

Table 2: Life expectancy of respondents in the town of Kribi

Length of life in Kribi	Total population	Percentages (%)
5 years	25	12.5
6 years	12	6
9 years	20	10
10 years	15	7.5
11 years	8	4
12 years	14	7
20 years	23	11.5
22 years	12	6
28 years	9	4.5
Native	62	31
Grand total	200	100

Source: October 2023 field survey

III-3-5. Assessment of the vulnerability and adaptation strategies of Kribi city dwellers in the face of rising surface temperatures

Vulnerability is assessed through the repercussions of temperature rises on the experiences and health of city dwellers. This analysis of vulnerability (using a questionnaire) was inspired by the work of Molina et al. (2023) on city dwellers facing extreme heat in the city of Nantes in France. The various illnesses linked to rising temperatures are recorded and analyzed using Excel 2013 software. The adaptation mechanisms developed by populations to cope with heat islands are also analyzed.

Overall, this questionnaire aims to collect data under the various headings mentioned above, in order to gain a better understanding of how the people of this seaside town are experiencing changes in land use and surface temperatures.

IV. Results

IV-1. Changes in land use in the town of Kribi

Since the early 1990s, the town of Kribi has experienced a resurgence, driven by the development of tourism, exploiting the region's many natural assets such as Ngoye beach, Lobé waterfalls, Ebodjé marine turtles, and the "feet in the water" hotels and colonial buildings (Tchindjang and Etoga, 2014). There has thus been a gradual change in land-use patterns over the years, linked to the multitude of developments and strong urban growth. Forest areas are being converted into buildings and road and port infrastructure. These changes in land use were observed in 2015, 2019, and 2023, and show a sharp decline in forest cover in the city.

IV-1-1. Land use dynamics in the town of Kribi between 2015-2023

In 2015, the period before the commissioning of the Kribi Autonomous Port (PAK), vegetation still occupied a significant area of around 5,169 ha, while built-up areas represented only 720 ha, with a standard deviation of 35. At that time, vegetation was largely dominant (Figure 3), representing 71 times the area occupied by buildings in and around the town of Kribi.

In 2019, the land area covered by vegetation falls to 4,908 ha and built-up area rises to 981 ha (261 ha), with a standard deviation of 37 (Figure 3). This period was marked by the entry into service of the autonomous port of Kribi (February 2018). This marked the beginning of a rush of people from all regions of Cameroon to Kribi, in search of work opportunities.

Finally, in 2023, the vegetation will have fallen dramatically and will now represent only around 2,516 ha, while the built-up area will have increased very rapidly to more than 3,373 ha, with a standard deviation of 65. This is the period of full activity for the autonomous port of Kribi (05 years).

We are therefore faced with spectacular urban development which, in 07 years, has irreversibly transformed the traditional forms of land use. We are now witnessing an environment that alternates the residues of natural formations dominated by human development. Saha & Tchindjang (2019) have already highlighted the rapid expansion of the city of Kribi and its environmental and socio-economic consequences, which include the degradation of forest cover and the multiplication of economic activities and facilities.

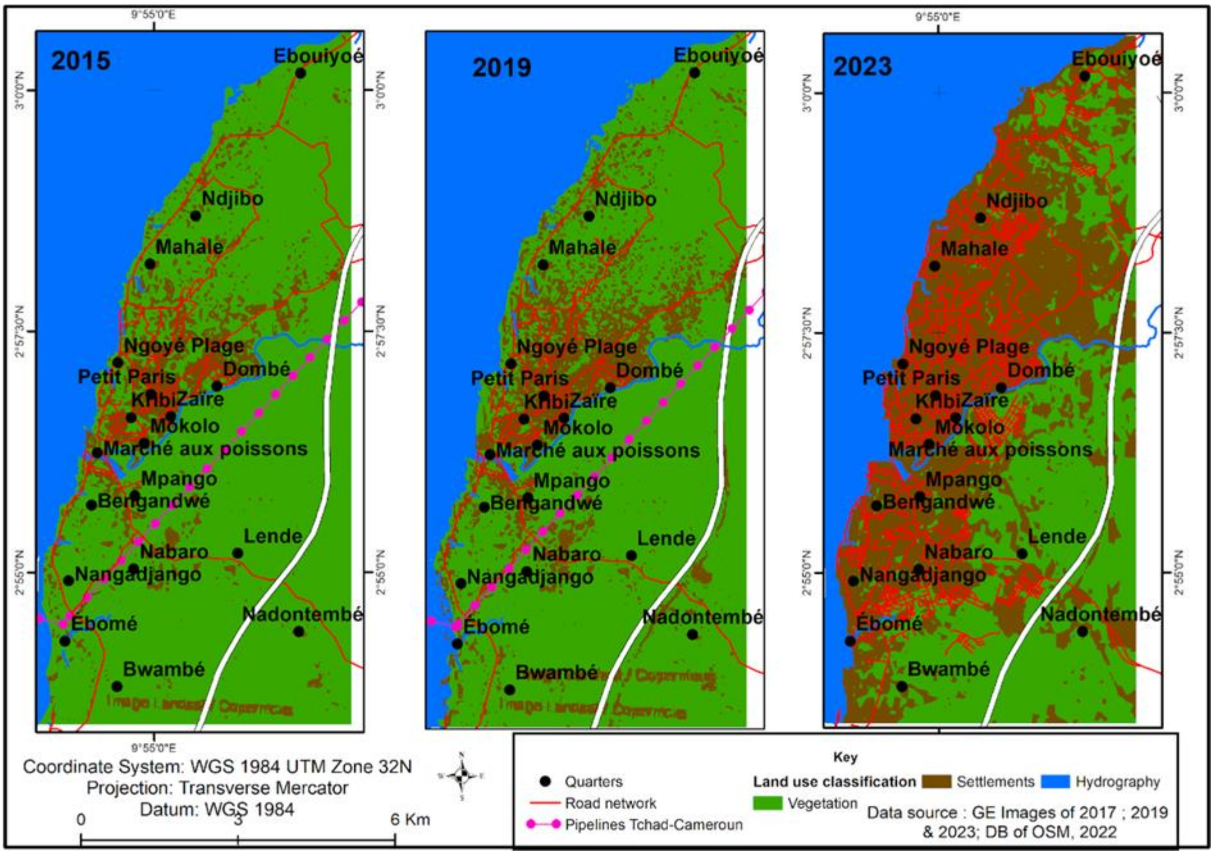

Figure 3: Dynamics of land use change around the town of Kribi, between 2015 and 2023, based on very high spatial resolution GE images

IV-1-2- Annual rate of change and vulnerability to change of land use classes in the town of Kribi

Between 2015 and 2019, following the commissioning of the Kribi Autonomous Port, vegetation cover has declined from 83% to 43%, representing a loss of 40%. Conversely, buildings have increased from 12% to 17%, representing an increase of 5% (Figure 4).

This trend continues between 2019 and 2023, with vegetation cover projected to diminish further from 83% to 43%, representing a loss of 40% of its surface area. Buildings are expected to expand significantly, increasing from 17% to 57%, representing a gain of 40%.

Vegetation is the most vulnerable land use class to change, being transformed by urbanization and port activities. The government's intention to establish Kribi as Cameroon's second economic hub has accelerated migration to the area. These anthropogenic pressures have led to substantial deforestation, resulting in a form of planned deforestation.

Field surveys corroborate these statistics, with over 82% of respondents acknowledging that the town's development has come at the expense of the dense forest that once dominated the landscape. This highlights the potential conflict between development and environmental protection, as previously noted by Kuété & Assongmo (2002). Moreover, 100% of respondents confirmed the rapid expansion of the urban fabric, particularly through the creation of new neighborhoods and the implementation of structuring projects (gas power station, Kribi Autonomous Port, etc.).

A significant 85% of the population expressed dissatisfaction with these land use changes and advocated for reforestation efforts. The environmental destruction is evident in the increase in erosion zones (with bare soil), the reduction in green spaces within the city, the disappearance of the forest, and the proliferation of buildings (figure 4).

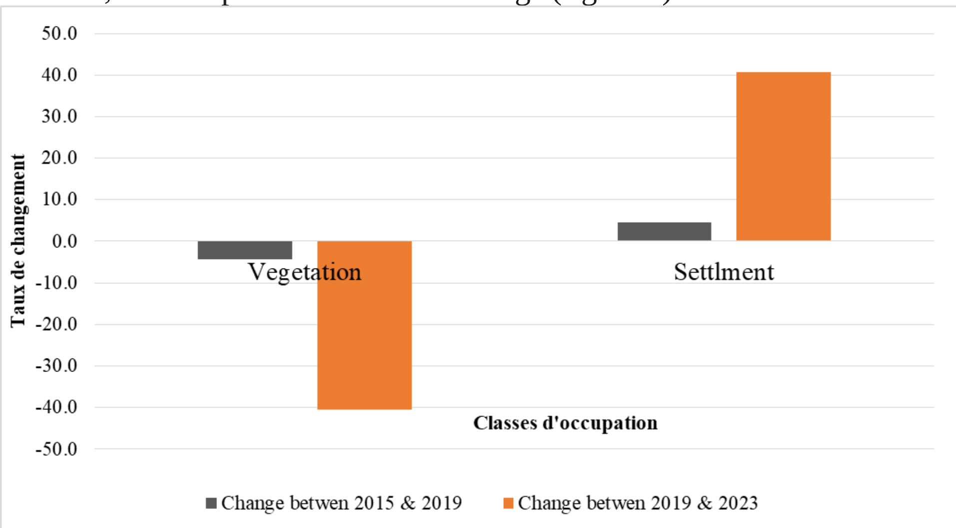

Figure 4: Rate of change in land cover around the town of Kribi, between 2015 and 2023. This rate is calculated from statistics generated from the classification of very high spatial resolution GE images

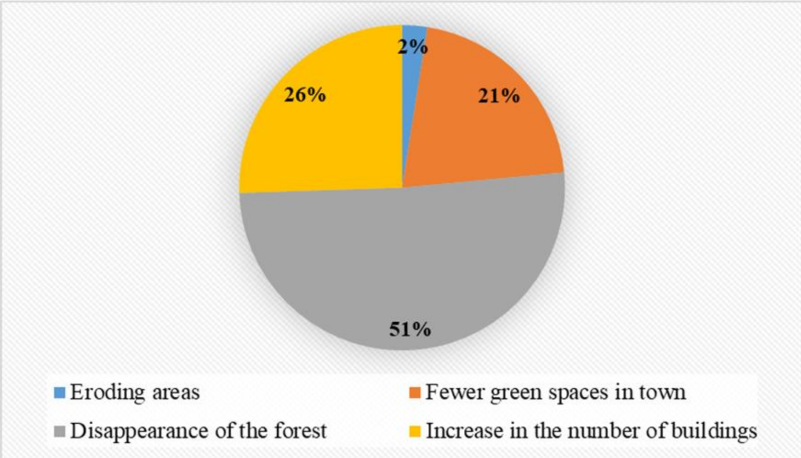

Figure 5: Spatial markers of environmental destruction in the seaside resort of Kribi (Source: field survey, October 2023)

These radical changes in land use patterns have significant environmental consequences, including the intensification of surface heat islands. The spatial variation of these heat islands is analyzed in the following section, between 2015 and 2023.

IV-2- Evaluation of surface temperature in the town of Kribi from Landsat 8 images

Surface temperatures are generated using Landsat 8&9 satellite images (bands 10&11). It appears that these surface temperatures have increased significantly and varied over time and space in the seaside town of Kribi, with 2017 being the exceptionally hot year. Mapping the spatial distribution of heat islands therefore appears to be a credible approach to better visualize this phenomenon (Foissard et al., 2013).

In 2015, surface temperatures in the city of Kribi were relatively mild, with more than 75% of the city having a temperature between 19 and 21°C. The average temperature was around 26°C, with the hottest area being the central core (31-33°C) (Figure 6).

The year 2017 was marked by an excessive increase in surface temperatures, with the number of areas with temperatures between 34 and 36°C increasing significantly (Figure 6). The average temperature hovered around 28°C.

As for 2019, the extreme heatwave of 2017 had passed, but the city of Kribi remained quite hot, with surface temperatures between 25 and 31°C. The average surface temperature fell back to 26°C. The town center still had the highest temperature values, at over 33°C (Figure 6).

Finally, in 2023, the town of Kribi will continue to heat up. The average surface temperature is around 28°C. Extreme temperatures (31-35°C) are recorded over almost the entire city (more than 80%). The lowest temperatures are found in the southern part of the city (20-25°C), where there is still a lot of vegetation (Figure 6). This rise in temperature is accompanied by significant demographic growth (more than 200,000 inhabitants by 2023) and an increase in the level of development in the city. For example, new districts such as *Dombè* and others have been subdivided, and new roads such as the Lolabé-Kribi motorway have been built. All this has been to the detriment of the vegetation cover. This date also marks five years of operation of the PAK, and therefore a major migration of the population to the new port Eldorado of Central Africa.

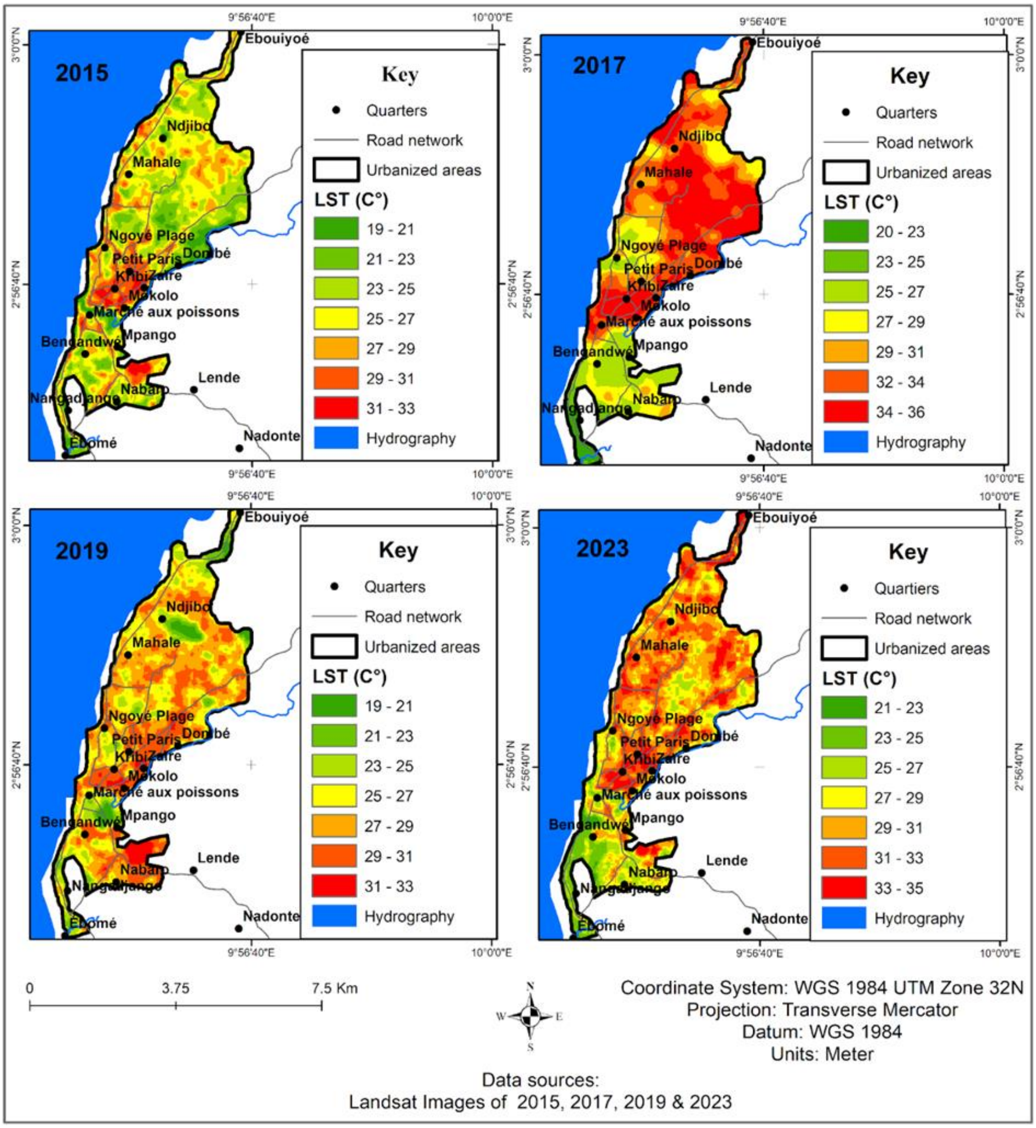

Figure 6: Variation in surface temperatures in the town of Kribi between 2015 and 2023, modelled from bands 10 and 11 of the Landsat 8 sensor

Based on field survey data, 98% of city dwellers surveyed in Kribi reported rising temperatures both inside and outside their homes. The main manifestations, as felt by the population, were extreme heat waves (24 people), high temperatures (52 people), medium heat (24 people) and the extension of the dry season (42 people) (Figure 7).

The hottest time of the day is between midday and the afternoon, according to 40% of respondents. Furthermore, 17% of the population felt that it was hot at all times of the day, and the only time when the air is cool is in the morning (6%) (Figure 8).

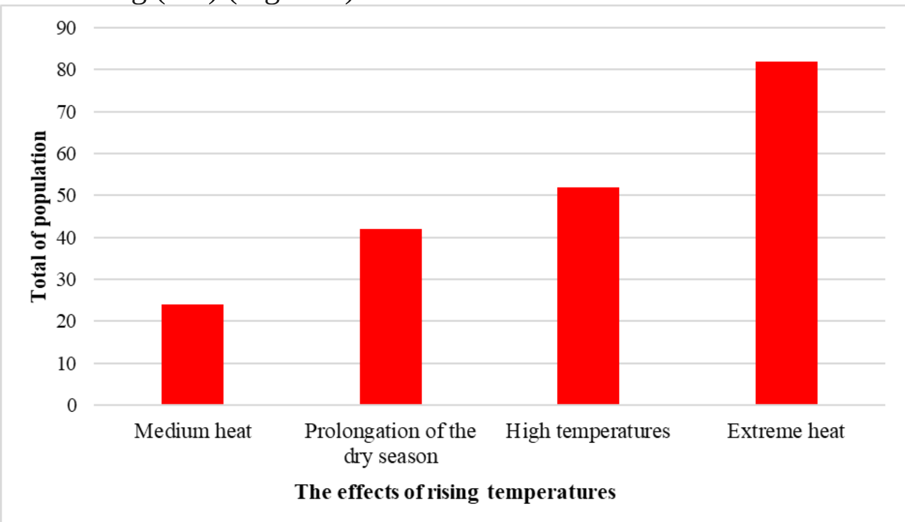

Figure 7: Manifestation of rising temperatures in the town of Kribi
Source: field survey of October 2023

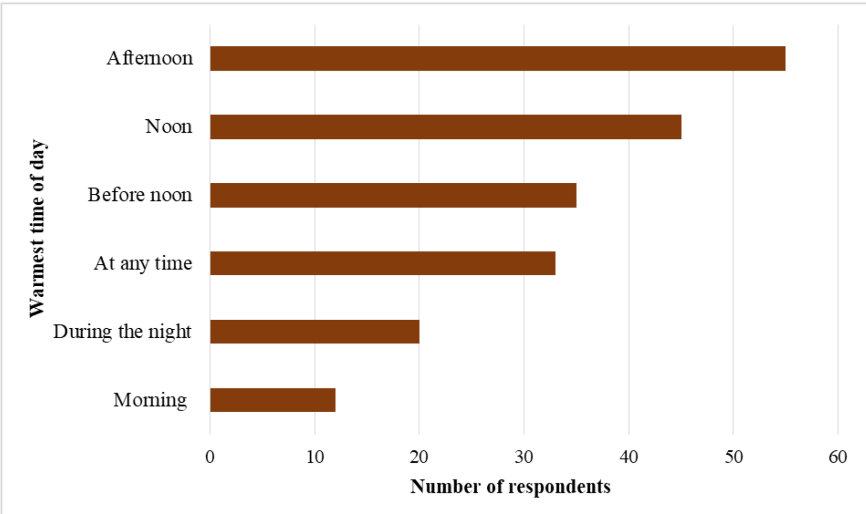

Figure 8: The hottest and least hot moments in the town of Kribi
Source: October 2023 field survey

IV-3- Correlation between changes in land use and the rise in surface temperatures in the seaside resort of Kribi

A cross-analysis of the spatial variation in surface temperatures (heat islands) as a function of changes in land use has established a correlation between the two. Zooming in on the urban center, we can see that in 2015, low temperatures (19-23°C) dominated the area, due to the presence of a large proportion of vegetation. In 2019, surface temperatures are starting to rise, at the same time as vegetation is retreating. Some districts, such as Dombè, which in 2015 had a surface temperature of between 19-21°C, will rise to 27-29°C.

By 2023, a period during which the city of Kribi has undergone remarkable spatial expansion, vegetation will have retreated drastically and irreversibly. As a result, surface temperatures also increased, with very hot zones dominating, with record temperatures of 33-35°C (Figure 9).

Soil sealing through the destruction of plant cover and the proliferation of buildings and road development therefore appear to be factors that amplify surface temperatures in the town of Kribi. This variation in surface temperatures also varies according to the level of sunshine and the nature of the objects on the ground. This is why areas covered by buildings tend to heat up more than those covered by forest.

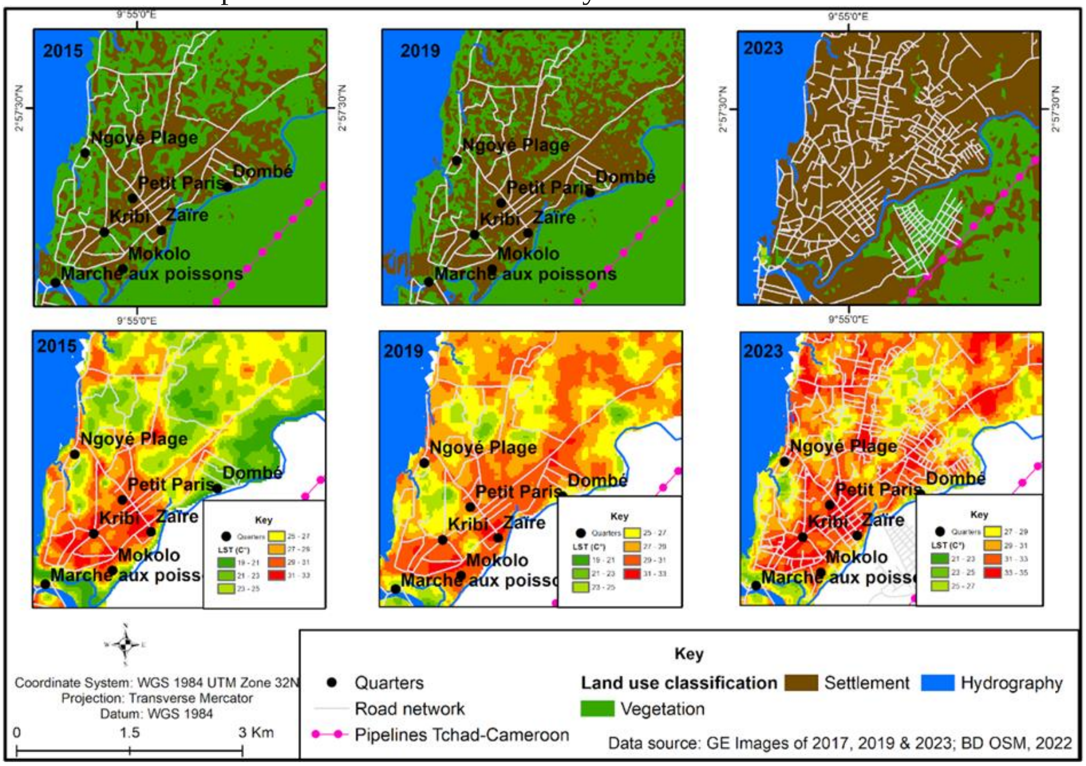

Figure 9: Correlation between changes in land use and changes in surface temperature in the town of Kribi

The data are collected in the Google Earth interface for the land-use classification, and on the USGS site for the Landsat images used to model surface temperatures in the town of Kribi.

Based on field surveys, more than 89% of the population believe that there is a close link between rising surface temperatures and changes in land use in the seaside town of Kribi. Only 3% said no, and 8% did not know whether such a link existed.

Faced with such high surface temperatures, city dwellers have to adapt by developing mitigation mechanisms. One of the most widely adopted mitigation methods is the use of air conditioning in homes and services. The players involved are legion, as are the brands of air conditioner used.

IV-4- Vulnerability of Kribi residents to heat islands and amplifying factors

People living in the city of Kribi are already vulnerable to increases in surface temperatures. This has a specific impact on their health and the discomfort it creates both inside and outside their homes. There are many factors contributing to these temperature rises, and therefore to the vulnerability of city dwellers.

IV-4-1- Vulnerability of Kribi residents to heat islands

Heat waves have an impact on the health of urban populations around the world. It makes them vulnerable, as can be seen from the illnesses and discomfort they suffer in the seaside town of Kribi. During the field surveys, when asked whether they were suffering from illnesses that could be linked to the rise in surface temperatures, the responses recorded more than 10 cases of illness. In order of importance, these included isolation, skin and eye diseases, exhaustion, asthma, and influenza (Figure 10). Added to this are night sweats inside houses, making it difficult for city dwellers to sleep. The situation is made even more critical by climate change, of which rising temperatures are one of the most widespread manifestations. The triple alliance of climate change, heat islands and health impacts is now becoming a reality (Levy, 2016).

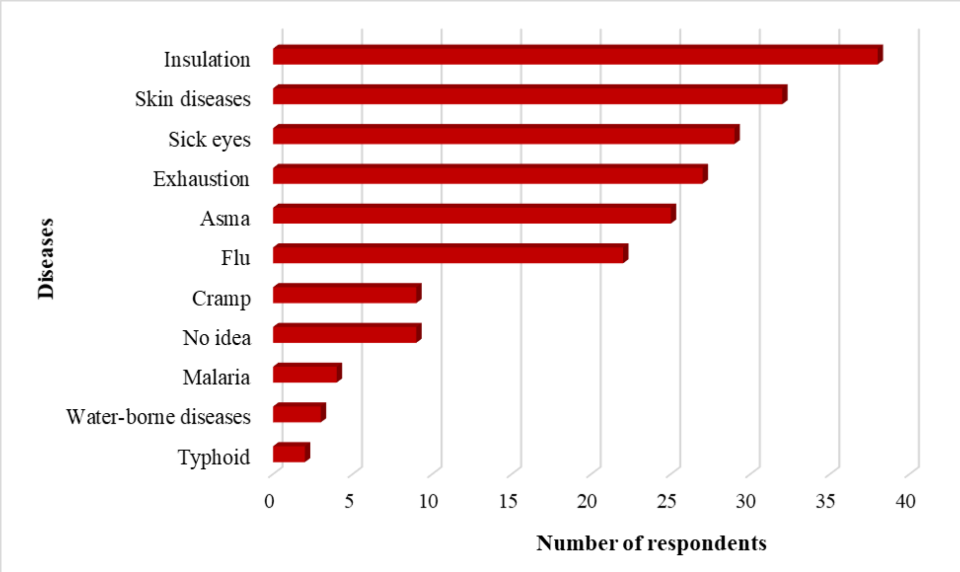

Figure 10: Factors amplifying the vulnerability of Kribi city dwellers to heat islands
Source: October 2023 field survey

IV-4-2- Factors Amplifying the Vulnerability of the Kribi Population to Heat Islands

Multiple factors contribute to the rising surface temperatures and, consequently, the climatic vulnerability of Kribi's urban dwellers. According to the questionnaire survey, 24% of respondents believe that vegetation destruction is the primary cause of their vulnerability to heat islands, followed by climate change (20%), intensified urban development (19%), population growth (16%), non-compliance with Kribi's land-use plans (9%), the concentration of all types of activities in the city (8%), and the presence of the Kribi Autonomous Port (6%) (Source: field survey conducted in October 2023).

However, there are sociological spatial inequalities in the way these populations experience vulnerability. (i) Those living closest to the urban center are the most vulnerable. Those who live further away experience heat islands differently because the periphery still has a high level of vegetation cover. (ii) Houses inhabited by multiple people are also the most vulnerable. 47% of those surveyed said they lived in a house with 3 to 5 people. This corroborates the statistics of the Institut National des Statistiques du Cameroun (INS, 2011), which estimates that there are, on average, 5.3 people per household in urban centers. Single parents or single parents with one child account for 15%.

When examining the size of the rooms, it becomes clear that most city dwellers live in very cramped rooms or studios, and it is easy to find more than three people in a room measuring 4 by 4 meters. As a result, indoor crowding also contributes to amplifying the heat in Kribi homes.

IV-5- Heat Island Adaptation/Mitigation Strategies in the City of Kribi

In response to rising surface temperatures in the town of Kribi, city dwellers are employing various strategies to mitigate the effects both inside and outside their homes. These strategies can be divided into two categories: those that can be implemented by political decision-makers and so-called operational strategies, whose implementation depends on the local population.

IV-5-1- Potential Adaptation Strategies That Require Political Will

Based on field survey data, more than 39% of respondents believed that green spaces should be rehabilitated. To achieve this, respondents suggested that every city dweller should be required to plant and care for a tree. Over 22% believed that building with mud bricks should be encouraged. Another 13% believed that the urban development plan should simply be respected. The various perspectives on heat island adaptation strategies in the city of Kribi are summarized in Figure 11 below.

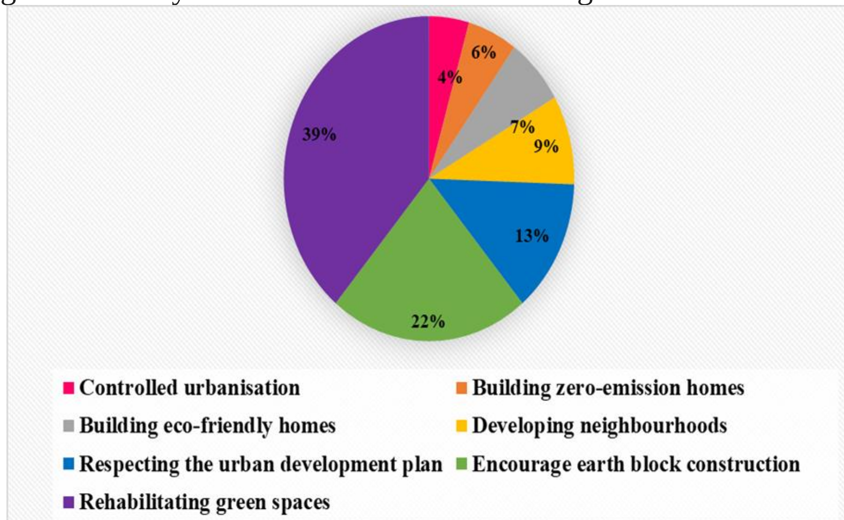

Figure 11: Heat island adaptation strategies that can be implemented in Kribi through political will (Source: October 2023 field survey)

IV-5-2- Operational Strategies for Heat Island Mitigation

These are the strategies that city dwellers can develop to reduce the perception of surface temperatures inside and outside their homes. The questions asked of city dwellers were designed to capture the different types of strategies adopted both inside and outside the home. The following results represent the responses of the 200 people interviewed for the survey. Based on the survey data, it appears that 41% of respondents believe that air conditioning can be used inside the home to reduce the feeling of hot flashes. This is a significant percentage for a small town like Kribi. Another 12% use fans. This second category is made up of average and/or low-income city dwellers who cannot afford the costs associated with air conditioner use. Table 4 summarizes other mitigation efforts, which can be categorized as actions taken both inside and outside the home.

Table 4: Summary of mitigation strategies for surface temperature increases in the city of Kribi. Representation model inspired by Molina et al., (2023)

No. of questions	Designation and question numbers	Question asked	Yes		No	
			N	%	N	%
Q403	Ventilation	Do you ventilate your home and create draughts in the morning and/or at night?	200	100%	00	00%
Q404	Use of shutters or curtains	Do you close the shutters, curtains... during the day?	50	25%	150	75%
Q405	Reducing the use of equipment that generates heat indoors	Are you reducing the use of heatproducing equipment (ovens, hobs, other household appliances)?	150	75%	50	25%
Q406	Changes to outdoor activities	Are you changing, reducing or cancelling some of your outdoor activities (sports, etc.)?	74	87%	26	13%
Q407	Reducing external travel	Reduce your daily travel outside the home	90	45%	110	55%
Q408	Change of timetable for outdoor activities	You change your working hours (work, shopping, etc.) (yourself or your employer).	65	33%	135	68%
Q409	Modification of activities in the home	Do you change, reduce or stop some of your activities in the home when it's very hot?	158	79%	42	21%
Q410	Occupation of cool rooms	You change all or part of your mode of transport (air-conditioned public transport, air-conditioned car, stop walking, cycling, etc.).	88	44%	112	56%
Q411	Spending time managing the temperature	Do you put wet washing in front of the windows and/or the fan?	41	22%	149	78%
Q412	Route changes	Are you changing the use of rooms, such as sleeping in a cooler room than your bedroom?	91	46%	109	54%
Q413	Wet linen and draught	Do you ventilate your home and create draughts in the morning and/or at night?	165	82%	35	18%

Source: October 2023 field survey

V- Discussion

V-1- Rapid Land Use Changes: A Result of Poorly Implemented Public Planning Policies

The spatial evolution of Kribi can be linked to the development of the Lolabé-Kribi motorway, which serves the port via the east of the town, the expanding agro-industries in the east, the growing tourism in the coastal area to the west, and the construction of the PAK to the south. These anthropogenic pressures have led to a significant reduction in dense forest cover, from 19,400 hectares in 1980 to 1,470 hectares in 2016 (a loss of 220 hectares per year). By 2020, dense forest has virtually disappeared, replaced by secondary forest and plantations.

This trend is confirmed by Landsat/Copernicus images posted on Google Earth, dating from 2013 and 2020. These images are particularly effective in understanding rapid land-use changes in the context of the interaction between human activities, the environment, and demographic growth (Hamud et al., 2021). The satellite images highlight the strong urban expansion of Kribi towards the north and northeast. Newly planned sites that were unoccupied in 2013 appear to have been fully developed in 2020, in just 8 years. Apart from this planned section, the town has expanded considerably in an uncontrolled manner towards the northeast. Kuété & Assongmo (2002) were therefore correct to speak of development against the environment on the Kribian coast.

V-2- Rising Surface Temperatures: A Direct Consequence of Land-Use Changes and Current Climate Change?

Urban sprawl at the expense of vegetation cover is a factor in changing surface temperatures and the proliferation of heat islands in the city of Kribi. The results of this research attest to this, and demonstrate the correlation that exists between these two variables. The only year that escaped this logic was 2017. Indeed, on a global scale, 2017 is considered to be the year in which the average temperature of the earth's surface exceeded pre-industrial temperatures by some 1.1°C. Clearly, on a global scale, the average temperature for the period 2013-2017 is the highest five-year average ever recorded (WMO, 2018). The city of Kribi has therefore not remained on the sidelines of global climate trends.

Data from NASA's satellite show this gradual increase in temperature in the town of Kribi. Between 1982 and 2020, average annual temperatures rose from 25.7°C to 26.5°C, with 2017 being the hottest year (Figure 12). This year was truly exceptional from a climatic point of view, felt throughout the world and of course in the town of Kribi.

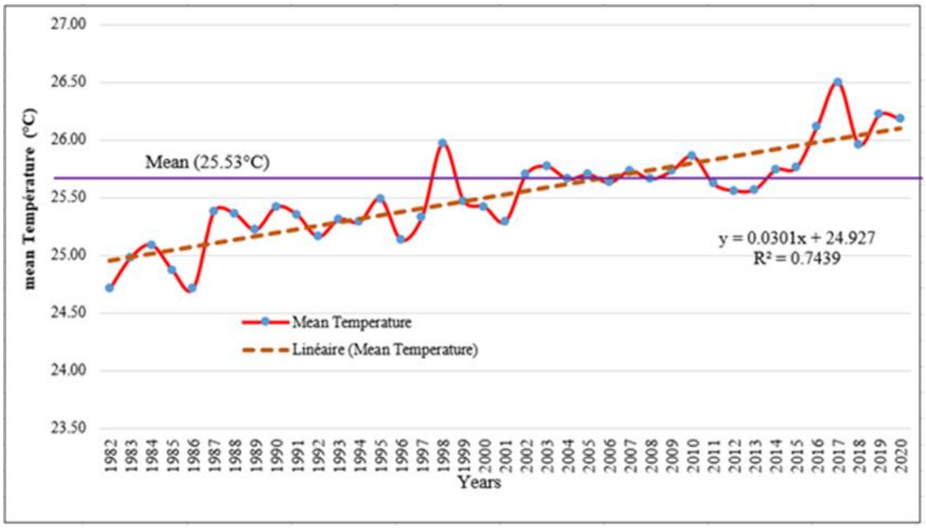

Figure 12: Variation in annual temperatures in the town of Kribi, between 1982 and 2020. Data from NASA satellite

The daily trends show a regressive trend from the first to the last day of the month. The hottest day was the third, with a temperature value of 25.55°C, and the least hot day was the thirtieth, with an average temperature of 25.43°C (Figure 13). There were some days on which temperatures remained almost stable. These were the days between the fourth-tenth day and the thirteenth-twentieth days. It was from the latter day onwards that temperatures fell slightly, dropping to 25.43 on the thirtieth day, before rising slightly to 25.46 on the thirty-first day. Overall, the temperature values did not deviate significantly from the mean, hence the standard deviation of 1.10.

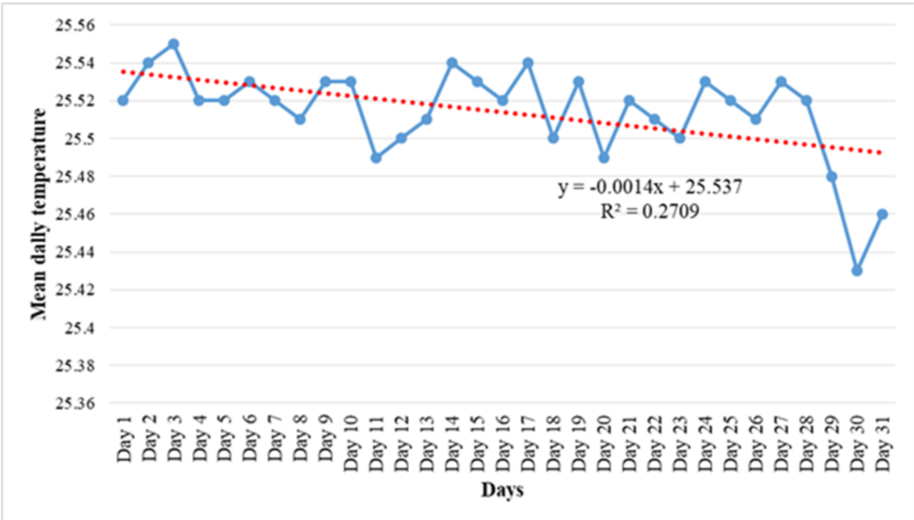

Figure 13: Variation in daily temperatures in the town of Kribi, between 1982 and 2020. Data from NASA satellite

Furthermore, based on analyses carried out by the Ministry of the Environment, Nature Protection and Sustainable Development (MINEPDED, 2015), in the National Climate Change Adaptation Plan (PNACC), Kribi is the fourth hottest coastal city in Cameroon, after Douala, Édea, and Limbe, respectively. Meteoblue data confirms this trend, as the analysis of maximum temperatures and hot days places Douala in first place, followed by Édéa (Figure 14).

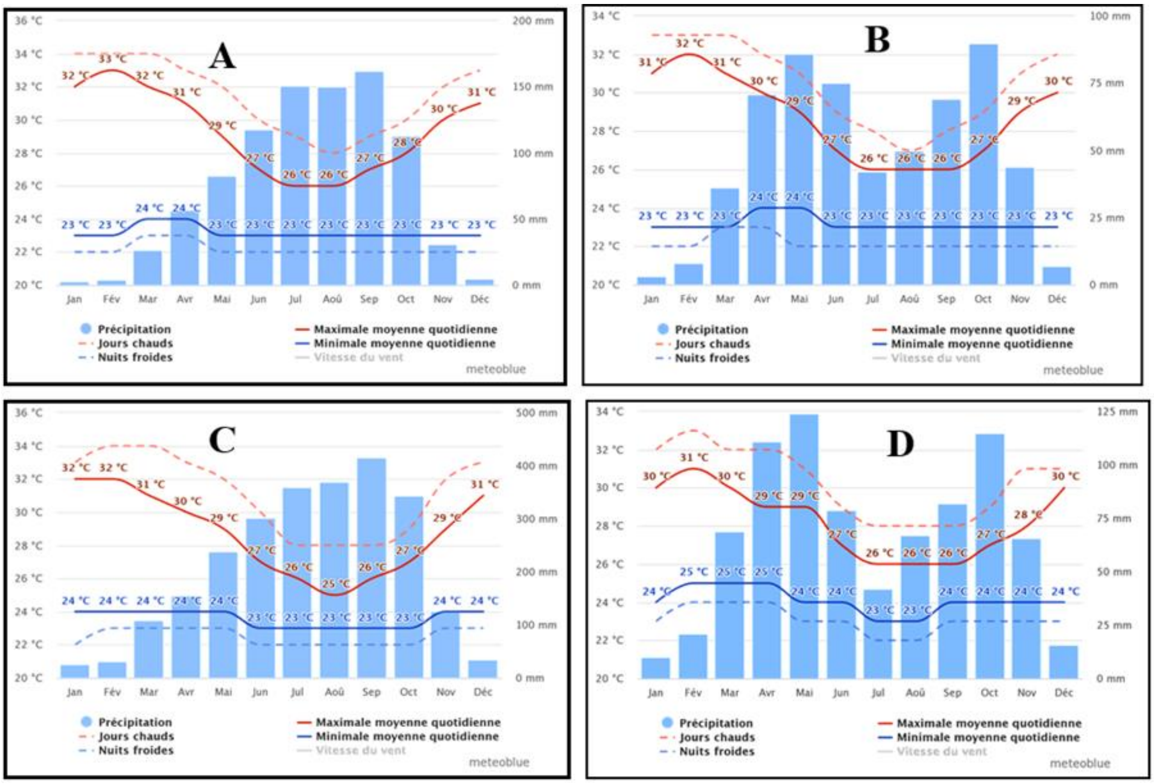

Figure 14: Umbrothermal diagram of four hottest coastal cities. A is the city of Douala; B is Édéa; C is the city of Limbé and D refers to the city of Kribi. The data is provided by the Meteoblue website (https://www.meteoblue.com/fr/meteo/historyclimate/).

V-3- Vulnerability of Populations to Heat Islands: A Reality in African Cities with Major Health Consequences

Urban heat islands (UHIs) pose a significant vulnerability for city dwellers, creating uncomfortable conditions both indoors and outdoors. This phenomenon is not limited to Kribi; when combined on a local scale, UHIs exacerbate the vulnerability of populations, affecting their health and daily lives. Field surveys in Kribi revealed an alarming number of heat-related illnesses, predominantly skin and respiratory diseases. Excessive heat can cause shortness of breath, weakness, and dry skin, making it a major thermal risk factor both at night and during the day (Kastendeuch et al., 2023). The situation is particularly critical for the elderly (Bungener, 2004), who are already susceptible to fatigue and health issues.

According to the French Red Cross Foundation (FCRF, 2023), the vulnerability of city dwellers to UHIs is a growing public health concern. Ymba (2022) conducted a study examining the socio-political dimensions of disasters, focusing on the effects of UHIs on the health of populations in Côte d'Ivoire. Her epidemiological survey of a sample of 1,066 people living in Abidjan identified the most vulnerable neighborhoods and the social and health consequences of UHIs for residents. The results demonstrate a clear link between high building density, UHI risk, and the health of residents. Major health problems include severe migraines, extreme fatigue, dry coughs, dizziness, fainting, and chest pains. These findings closely mirror our observations in Kribi.

V-4- Adaptation Strategies: A Reliance on Air Conditioning

This study concluded that the widespread use of air conditioning as an adaptation strategy to UHIs in Kribi is a direct consequence of rising surface temperatures and the proliferation of heat islands. Reducing the vulnerability of city dwellers to UHIs is imperative (Haouès-Jouve & Hidalgo, 2014). Air conditioning appears to be an effective solution, providing city dwellers with comfortable, cool indoor conditions. This fresh air is essential, making rooms habitable when ambient temperatures reach around 35°C in Kribi. Low-income city dwellers rely on fans, while the poorest simply ventilate their homes. The latter try to minimize heat-generating activities indoors.

Outside their homes, Kribi residents struggle to combat UHIs. They are often forced to endure the intense heat while going about their daily lives. Maillard et al. (2014) propose a solution based on the humidification of pavements in large cities, citing the example of Lyon, France.

With rising global temperatures (Wyard et al., 2018), coastal towns like Kribi are becoming increasingly vulnerable. Air conditioning consumption is dominated by the tertiary sector, accounting for 71% of total usage. This sector also accounted for 80% of air conditioning use in France in 2003 (Gaz de France, 2003). Around 20% of this demand was due to indoor activities (computer rooms, laboratories, etc.) in 2000 (Deleval, 2000), increasing to 30% in 2018, according to statistics from the French Environment and Energy Management Agency (ADEME, 2018). A Europe-wide study forecasts significant electricity consumption (more than 10 exajoules) linked to air conditioning use (Abergel & Jordan, 2019). This excessive air conditioning use poses challenges for both homes and the environment.

The following section discusses the limitations associated with air conditioning use and the prospects for mitigating heat islands in the context of the Millennium Development Goals (MDGs).

V-5- Constraints Linked to the Use of Air Conditioning

The first constraint is energy (Fondja Wandji, 2011). The State of Cameroon struggles to meet household electricity demand due to supply shortages. This deficit leads to frequent and prolonged power outages. In Kribi, for instance, residents experience at least 2 to 3 power cuts daily, especially during the dry season when reduced river flow limits electricity generation. Privatizing the electricity production company is therefore seen as a violation of consumer rights (Etogo Nyaga 1, 2020). ENEO's current management faces widespread criticism from the population, not only for untimely power cuts but also for the dilapidated state of power transmission equipment, the responsibility of the national electricity transmission company (SONATREL). Increasing the number of air conditioners in homes and businesses is inappropriate in this context.

The second constraint is environmental, particularly indoors. Water waste and greenhouse gas emissions are the main sources of pollution, deteriorating the quality of indoor comfort in both residential and hotel buildings (Dalel & Ammar, undated; Tahar, Guermit, 2019). Additionally, cooling indoor spaces.

V-6- Prospects for Reducing Air Conditioning Use in Kribi Homes

Collaboration with the West to "*Enhance the thermal performance of the building stock, which accounts for nearly 40% of the global energy savings potential for heating and cooling (IEA, 2019)" is a viable option. The widespread adoption of so-called "zero-emission" buildings and the deep renovation of the existing building stock would cumulatively save, by 2050, the equivalent of all the energy consumed by the G20 countries in 2018 (IEA-UN Environment, 2017).*" (Abergel & Jordan, 2019).

This represents a technology transfer in the field of building engineering and aligns perfectly with SDG 17, which advocates for partnerships to achieve sustainable development goals. Several solutions exist to address the excessive use of air conditioning in homes and reduce energy costs.

V-6-1- Within Buildings

One of the most practical measures within buildings would be to install multi-split systems. This appliance allows for air conditioning of multiple offices or rooms, with indoor units connected to a single outdoor unit (Deleval, 2000). Coulibaly & Coulibaly (2010) propose the use of solar air conditioners for homes in sub-Saharan Africa. This green solution would significantly reduce the energy demand for air conditioners, as well as their environmental impact. This second solution appears to be more sustainable due to its reliance on renewable energy. This aligns with MDG 7, which calls for affordable and clean energy.

V-6-2- Outside Buildings

Promoting urban ecology (green spaces) appears to be an effective solution for combating heat islands in Kribi. The city needs to be greened, creating outdoor refuge areas where residents can move around in an attempt to improve their comfort (Molina et al., 2023). This would allow residents to experience the city's freshness (Ameglio Ngao & Saudreau, 2019). This urban vegetation appears to be a means of cooling and mitigating urban heat islands (Lamine, 2023) and preventing heatwaves (Lauffenburger, 2010).

Raymond and Simon (2012) support this idea and demonstrate that urban history has witnessed a permanent coexistence between urban and ecological facts since ancient times. For them, nature has always been present in the city, regardless of the will of city dwellers and urban planners. Some authors, such as Saint Laurent (2002); Saint-Arnaud, M. (2008); and De Vreese (2019), compare these islands of vegetation to "urban islands," drawing inspiration from the biogeographical island theory of Robert MacArthur of Princeton University and Wilson of Harvard, recently taken up by Clergeau, who applies it to the urban level. These isolated green spaces in the city are, in a way, island spaces subject to modes of dispersion and biological exchange similar to those of vegetation on oceanic islands isolated from the mainland, for example. Landolt (2001) makes a similar point, referring to the city of Zurich, which is home to more than 1,211 plant species, almost twice as many as an equivalent area on the Swiss plateau. A recent study carried out in the city of Douala (Cameroon's economic capital) (Mahguoh, 2022) also highlights the need to promote open spaces in this city of over 4 million inhabitants, which is suffocating under the weight of heat islands, in order to ventilate it better. This aligns with MDGs 11 and 13, which call for sustainable cities and communities and the fight against climate change, respectively.

Finally, for the city of Abidjan in Côte d'Ivoire, Ymba (2022) proposes avenues for urban resilience to climate change and heat islands, such as revegetation, the development of early warning systems, and the application of building norms and standards. These are the same recommendations we have arrived at in this study, based on local perceptions recorded by questionnaire.

Conclusion

This study on urban heat islands has examined how changes in land use and the rise in heat islands, exacerbated by climate change, contribute to the vulnerability of urban dwellers in the Cameroonian coastal and port city of Kribi. Changes in land use are the primary cause of the increasing prevalence of heat islands. In some areas of Kribi, temperatures reach up to 35°C. Urban residents are already highly susceptible to these increases in surface temperature, as evidenced by the prevalence of respiratory and skin diseases. In response to this situation, city dwellers have adopted adaptation strategies both inside and outside their homes. Among the various adaptation strategies employed, air conditioning usage has the highest adoption rate, with 41% of respondents reporting its use. Other strategies include using fans, opening shutters, and limiting heat-generating activities inside the home. This extensive use of air conditioning warrants further investigation, considering the stakeholders involved, the most commonly used brands, and the areas or neighborhoods with the highest usage rates. Such an investigation will facilitate establishing a connection between changes in land use, rising surface temperatures, and air conditioning usage in the coastal town of Kribi.

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