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Impacts of Land Use Change on Urban Heat Islands in Kribi, Cameroon: Assessing Vulnerability and Adaptive Strategies

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Abstract

Urban heat islands (UHIs) represent a significant manifestation of climate change impacting cities globally. 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 considerable risks to vulnerable urban populations. Notable cities experiencing this phenomenon include Lagos (Nigeria), Cairo (Egypt), Johannesburg (South Africa), Nairobi (Kenya), and Dakar (Senegal). This study investigates the interplay between land-use changes, the emergence of heat islands, and the vulnerability of residents in the seaside and port city of Kribi, Cameroon. Furthermore, it explores effective adaptation strategies to mitigate the impacts of heat islands. Google Earth (GE) imagery from 2015, 2019, and 2023 is utilized to assess land-use dynamics. Surface temperatures are analyzed for 2015, 2017, 2019, and 2023 using Landsat 8 and 9 imagery processed with QGIS 2.18 software. Meteoblue meteorological data are employed to validate the findings. A GPS survey of air conditioners in Kribi, conducted using the SWMap mobile application, provides insights into stakeholder involvement and the categories of air conditioning units. Additionally, a questionnaire administered to 200 city dwellers gathers information on their vulnerability to heat islands and their mitigation strategies. It also carries out a prospective analysis of the evolution of urban heat islands in the city of Kribi using linear regression and statistical modeling approaches. Currently, surface temperatures in Kribi are estimated to range from 26°C to 35°C between 2015 and 2023, with notable spatial variations in heat islands. The projection to 2033 (10 years) shows that heat islands will intensify, although temperature values will remain more or less the same. To cope with these rising temperatures, most building occupants rely on air conditioning. Over 41% of surveyed residents use air conditioning in their homes, with the highest proportion found in hotel and catering facilities (52%), followed by service offices (16%) and private residences (14%). Green space in Kribi has drastically declined from 2015 to 2023. In 2015, green space accounted for 5,169 ha (83%), but by 2023, it had shrunk to 2,516 ha (43%), resulting in a loss of 2,653 ha. This decline was evident between 2015 and 2019, with green space decreasing from 4,908 ha (83%) to 2,516 ha (43%). The study underscores the importance of integrated management of urbanization and natural resources to address the challenges posed by climate change and rapid urbanization. It also discusses the implications for other African countries. This approach will not only aid in identifying solutions tailored to Kribi but will also generate more general recommendations applicable to other cities facing similar challenges related to urbanization and climate change.

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

I. Introduction

Urban surface temperatures are characterized by the phenomenon of urban heat islands (UHIs), which refer to metropolitan areas experiencing significantly higher temperatures than their surrounding rural regions. This temperature disparity arises due to the presence of natural areas in rural settings that help mitigate solar radiation and reduce surface temperatures (Doutreloup et al., 2022). Countries along the Gulf of Guinea, like many others, are grappling with rapid urban growth (Losch & Magrin, 2016), resulting in extensive urban sprawl that encroaches upon natural environments (Mbaha & Tchounga, 2020; Essono Milla, 2022). This urban expansion is accompanied by rapid demographic increases (Tabutin, 1991; Leridon, 2015; Delaunay & Guengant, 2019), leading to the degradation of in situ vegetation cover (Rudel, 2013; Eloy & Le Tourneau, 2009; Petrişor et al., 2020). Such

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degradation contributes to rising surface temperatures (Wan Mohd et al., 2020) and exacerbates the urban heat island effect. It is essential to curb these land-use changes to mitigate their environmental impacts. Xiang et al (2024) provide a detailed analysis of the spatiotemporal evolution of the urban heat island effect in Changsha, through the prism of local climate zones. The results provide valuable insights for urban planners and policymakers, contributing to more effective approaches to mitigating the impacts of UHI in urban areas. To understand the dynamics of land conversion, remote sensing technologies have been employed, as they have advanced significantly (Rogan & Chen, 2004) and are widely utilized in the global study of land use change (Green et al., 1994). Studies by Wu et al. (2006), Alqurashi and Kumar (2013), and Letsoin et al. (2020) have successfully monitored and detected land cover changes using these technologies. Carleer et al. (2005) and Grippa et al. (2018) have demonstrated the importance of satellite image segmentation for monitoring and mapping land cover changes in urban areas. Millogo et al, (2024) provide an in-depth analysis of land use and land cover dynamics in the Dinderesso and Peni forests, highlighting the challenges associated with deforestation and ecosystem degradation in Burkina Faso. The results provide crucial information to guide conservation and sustainable development efforts in the region.

In tropical Africa, Lambin et al. (2003) conducted spatial modeling of land use change factors based on satellite images, assessing the efficacy of this approach in predicting the location and extent of land use changes. More recently, Qiao et al, (2024) highlight how remote sensing and a local climate zone approach can be used to better understand the factors that contribute to the urban heat island effect while providing recommendations for sustainable urbanization. Akalu et al. (2019) applied remote sensing to monitor land use changes in a sub-catchment in eastern Ethiopia. In Morocco, Barakat et al. (2019) utilized remote sensing images to evaluate the environmental impacts of land degradation and land use in the Beni-Mellal district. Khan et al.,(2024) show a positive correlation between urbanization and increases in surface temperatures, which has important implications for urban planning and resource management. The article highlights the need to integrate sustainable development strategies to mitigate these effects. Ning et al (2024) explore the differentiation of the urban heat island effect (UHI) according to the characteristics of the local climate zones (LCZ). It uses spatial analysis methods to examine temperature variations across different LCZs, taking into account remote sensing data and climate records. This makes it possible to visualize how temperatures vary according to local characteristics.

In Cameroon, Fonge et al. (2019) and Zekeng et al. (2019) investigated land use changes in peri-urban protected areas, focusing on the Barombi Mbo reserve and the Doumé communal forest, respectively. In the Douala-Edéa

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Faunal Reserve, Kana et al. (2019) utilized high-resolution imagery (Spot 5 and Google Earth) for supervised and unsupervised classification to map forest dynamics in this ecologically significant area surrounding Douala. Similarly, the Cameroonian consultancy Action for Sustainable Development (Nguénang, 2015) conducted research on the spatio-temporal dynamics of the Douala-Edéa Faunal Reserve as part of the GEOFORAFRI projects, highlighting areas of degradation using a multi-sensor remote sensing approach across three Landsat periods (TM, ETM, and OLI).

Google Earth (GE) imagery is particularly useful for understanding land cover and identifying land use patterns (San Emeterio et al., 2021), despite the tendency to overestimate ground observations by 1% and underestimate them by 8.3% (Frankl et al., 2013). These images are frequently used in various studies to validate results, despite their limited spectral characteristics (consisting solely of red, green, and blue (RGB) wavelengths). Hu et al. (2013) recommend utilizing GE images to address land cover issues. For instance, Hamud et al. (2021) monitored urban expansion and land use changes in Banadir, Somalia, using GE imagery. Zurqani et al. (2019) analyzed urban grids, while Zhao et al. (2021) conducted spatial-temporal analyses of land use changes in Hangzhou Bay, China, employing GE imagery.

In Cameroonian cities, Duna et al. (2021) assessed the spatial dynamics of Yaoundé using satellite images, incorporating GE images as a validation source. To the south of Douala airport, Bengono Nkodo (2021) used GE and Pleiades imagery to monitor the impacts of urbanization on the mangrove coastal area of the Wouri estuary. In Kribi, previous studies have examined land use changes using Landsat images with low spatial resolution (30 m). For example, Saha and Tchindjang (2019) evaluated the spatiotemporal dynamics of Kribi, highlighting environmental factors and consequences, while Mbevo et al. (2018) analyzed landscape dynamics from 1984 to 2016, indicating a tendency for the city to expand into its hinterland.

These shifts in land use patterns influence surface temperatures (Ghilain et al., 2023), necessitating analysis to identify heat islands. The correlation between land use changes and surface temperatures has been widely studied globally. Devendran and Banon (2022) examined spatio-temporal variations in land use changes and their effects on surface temperatures in Accra, Ghana, utilizing Landsat imagery. Kalma et al. (2008) developed a remote sensing method for measuring surface temperatures and highlighting heat islands based on surface evaporation estimates. Jiménez-Muñoz et al. (2014) employed Landsat 8 imagery to measure surface temperatures, while Guha et al. (2018) used the same source to assess surface temperatures in Florence and Naples, applying the normalized vegetation index (NDVI) and the normalized built-up index (NDBI) to understand the

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interactions between incident solar radiation and vegetation or built environments.

In Cameroon, Nguemhe et al. (2018) evaluated surface temperatures in Douala using Landsat images. Jin Aik et al. (2020) studied the relationship between variations in surface temperatures and land use changes in the agroecological zones of the high savannahs of West Cameroon, a region significantly impacted by agricultural and pastoral activities (Morin, 1994). More recently, Ebodé (2023) highlighted variations in surface temperatures concerning land use in the Mefou catchment area of Central Cameroon.

In the context of ongoing climate change, heat islands are increasingly prevalent both spatially and in their impacts, heightening the vulnerability of urban populations and adversely affecting their health (Levy, 2016) and comfort levels inside and outside buildings (Molina et al., 2023). Mena et al. (2016) have documented rising temperatures in Kribi, negatively impacting residents of this coastal city, leading to the adoption of de facto mitigation mechanisms by urban populations. The most common response among the residents of Kribi has been the increased use of air conditioning and fans.

Regardless of geographical location, air conditioning is an effective means of combating rising temperatures, particularly indoors (Zélem, 2007; Giguère, 2009). Popular perception suggests that air conditioning enhances well-being and significantly reduces discomfort in buildings (Drapeau, 2021). Thus, it is crucial to maintain cooler indoor environments for greater comfort (Ameglio et al., 2019). The demand for air conditioning has surged in response to climate change (Gaaloul & de l'Environnement, 2021), as extreme temperatures become more pronounced indoors. This urgency likely motivated Anquez and Herlem (2011) to investigate the causes, impacts, and potential solutions to rising heat islands in urban centers. Sentenac (2016) modeled scenarios for reducing heat islands by 2050 in the metropolitan community of Montreal amid climate change challenges.

In various African cities, relevant studies have addressed urban heat islands. Akinbode and Adejuwon (2020) reviewed research on urban heat islands in Africa, analyzing causes, effects, and mitigation strategies. Their findings indicate that urban heat islands are a significant concern in Africa due to rapid urbanization, with climatic factors, population density, and land use contributing to the phenomenon. Proposed mitigation strategies include the establishment of green spaces, improved waste management, and the use of reflective building materials.

Likewise, Olayinka and Njoku (2019) assessed the impact of urban heat islands in Lagos, Nigeria, utilizing temperature and humidity data. They concluded that the average temperature in Lagos is 2°C higher than the average rural temperature, with densely populated urban areas being particularly susceptible to UHIs. Strategies such as creating green spaces and

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reducing atmospheric pollution could alleviate the urban heat island effect. Mubanga and Munishi (2018) examined urban heat island mitigation strategies in Africa, emphasizing nature-based solutions, with findings indicating that urban green spaces can lower temperatures by 1 to 3°C. Green roofs and walls are also effective in mitigating urban heat islands. Urban policy must integrate UHI mitigation strategies to enhance the quality of life for city inhabitants.

II. Presentation of the Town of Kribi

Kribi, a coastal town situated in the Gulf of Guinea along the shores of Cameroon, is located at the mouth of the Kienké River. Covering approximately 20,300 hectares, Kribi is administratively part of the South Region and the Ocean Department, serving as the capital of the Kribi district. The town is divided into two communes: Kribi 1er and Kribi 2ème (Figure 1). The climate in Kribi is classified as humid equatorial, influenced by the monsoon, a characteristic typical of coastal regions (Suchel, 1988). The town experiences an average annual rainfall of approximately 2,900 mm. The primary dry season occurs from December to March, with average monthly rainfall of 262 mm. Conversely, the main rainy season spans September to November, averaging over 1,183 mm of precipitation (Mena et al., 2016).

Temperatures in Kribi remain relatively high, with a diurnal temperature range of approximately 2.42 degrees Celsius. Maximum temperatures typically range from 26°C to 31°C, with peaks often occurring 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, with humidity levels reaching up to 83% depending on the time of day.

Kribi's origins date back to the colonial era (Bahuchet, 2010), contributing to its structured spatial and administrative organization. The town was initially inhabited by the Batanga, Mabi, and Bagyeli peoples. Kribi is among the Cameroonian cities that have experienced a nearly four-fold population increase between 1976 and 2010, rising from 11,261 to 59,928 residents. A 2022 estimate places the town's population at approximately 200,000. This demographic growth has been accompanied by significant spatial expansion, particularly following its transformation into a port city with 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).

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

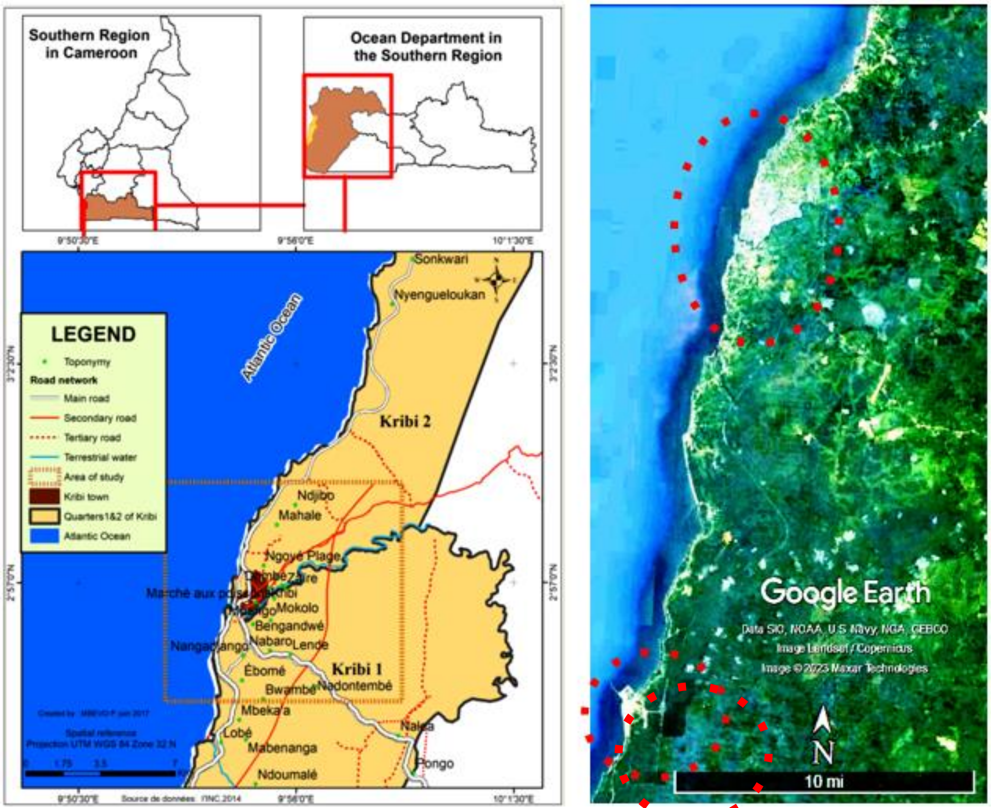

Figure 1: Location map of Kribi on the Coast of Cameroon

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.

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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):

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

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)

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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

III-2-1- 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, employing the RS&GIS plugin. This tool applies well-defined algorithms to raw satellite data to generate outputs such as Land Surface Temperature (LST) in degrees Celsius, Satellite Brightness Temperature, Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) (Kamal et al., 2022).

For the calculation of LST, the algorithm utilizes Landsat 8 bands 10 and 11, which are thermal infrared (TIR) bands capable of detecting heat emitted from the ground during image acquisition. Unlike weather stations that measure air temperature, these bands record ground temperatures, which are typically higher. The images analyzed were acquired in 2015, 2017, 2019, and 2023, ensuring consistency by capturing them at the same time of day and during the same season (see Table 1).

Table 1: Characteristics of Landsat satellite image bands used to calculate urban heat islands

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-2-2- Prospective analysis of the evolution of heat islands in the city of Kribi in 2033

To achieve this, we adopted two complementary approaches: linear regression and statistical modeling.

The linear regression method uses linear regression to project the future evolution of heat islands, as a function of explanatory variables such as building intensification rates, population growth, and land use conversion (Santer et al., 2013). Using 2015 as the reference year, we established an average rate of change for these different variables, which served as a reference for the 10-year projection.

The statistical modeling method involves using statistical modeling techniques to project the future evolution of heat islands, as a function of the explanatory variables mentioned above (Tebaldi & Knutti, 2007). It was this

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modeling approach that was used to spatialize the projected temperature values and produce a map of urban heat islands in the city of Kribi in 2033.

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 (Figure 2). 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).

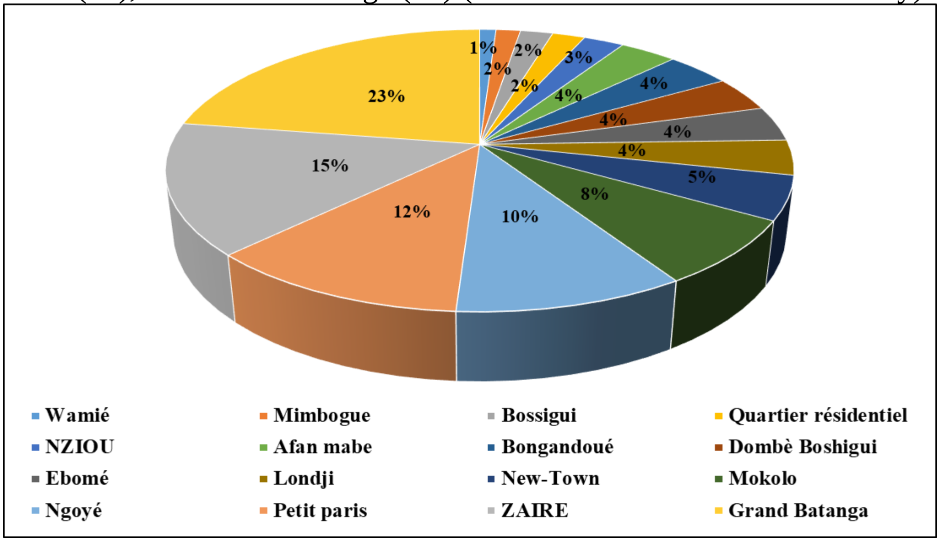

Figure 2: Localities surveyed in the town of Kribi, with the percentages of the population surveyed. (Source: October 2023 field survey)

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% of

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respondents had completed primary education only, 29% had secondary education, and 69% had tertiary education. Finally, age ranges varied from under 25 to over 65 (Figure 3).

Figure 3: 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

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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, prior to the commissioning of the Kribi Autonomous Port (PAK), vegetation covered a substantial area of approximately 5,169 hectares, while built-up areas encompassed only 720 hectares, exhibiting a standard deviation of 35. At this time, vegetation was predominant, occupying an area 71 times greater than that of built environments in and around the town of Kribi (Figure 4).

By 2019, the area covered by vegetation had decreased to 4,908 hectares, while the built-up area increased to 981 hectares, reflecting a change of 261 hectares and a standard deviation of 37 (Figure 4). This period coincided with the operational launch of the Kribi Autonomous Port in February 2018, which initiated a significant influx of individuals from various regions of Cameroon seeking employment opportunities.

In 2023, vegetation had declined dramatically to approximately 2,516 hectares, whereas the built-up area had escalated rapidly to over 3,373 hectares, with a standard deviation of 65. This period marks a time of peak activity for the Kribi Autonomous Port, five years after its establishment.

The data illustrate a remarkable transformation in land use within just seven years, resulting in irreversible changes to traditional land patterns. We now observe an environment characterized by remnants of natural formations that are increasingly overshadowed by human development. Saha & Tchindjang (2019) have previously emphasized the rapid expansion of Kribi and its associated environmental and socio-economic consequences, including

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the degradation of forest cover and the proliferation of economic activities and infrastructure.

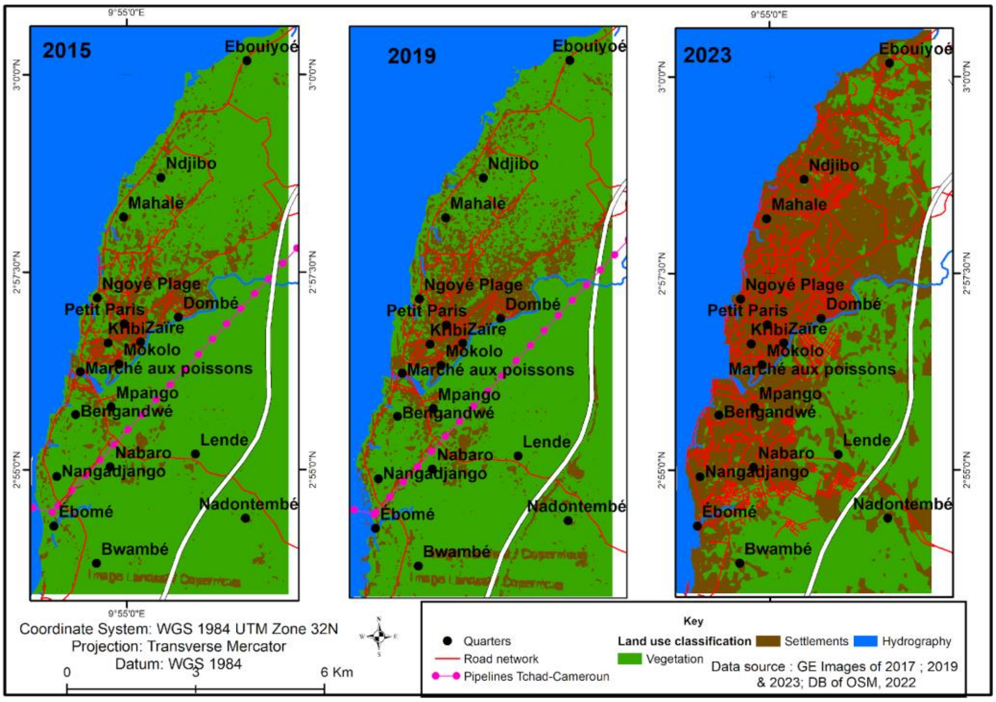

Figure 4: Dynamics of land use change around the town of Kribi, between 2015 and 2023, based on very high spatial resolution GE images. (Data source: Landsat image processing)

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 experienced a significant decline from 83% to 43%, representing a loss of 40%. In contrast, the proportion of built environments increased from 12% to 17%, reflecting a gain of 5% (Figure 5). This trend is projected to continue between 2019 and 2023, with vegetation cover expected to diminish further from 43% to 3%, indicating an additional loss of 40%. Meanwhile, the built-up area is anticipated to expand substantially, rising from 17% to 57%, which corresponds to a gain of 40%.
Vegetation emerges as the most vulnerable land use class, increasingly transformed by urbanization and port-related activities. The government's objective to position Kribi as Cameroon's second economic hub has intensified migration to the area, resulting in significant anthropogenic pressures that have led to substantial deforestation and a form of planned deforestation.

Field surveys support these findings, revealing that over 82% of respondents acknowledged that the town's development has occurred at the

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expense of the dense forests that once characterized the landscape. This situation underscores the potential conflict between development and environmental protection, as previously highlighted by Kuété & Assongmo (2002). Furthermore, 100% of respondents confirmed the rapid expansion of the urban fabric, particularly through the establishment of new neighborhoods and the implementation of major projects such as the gas power station and the Kribi Autonomous Port.

A notable 85% of the population expressed dissatisfaction with these changes in land use and advocated for reforestation initiatives. The environmental consequences are evident in the increasing erosion zones characterized by bare soil, the reduction of green spaces within the city, the disappearance of forested areas, and the proliferation of buildings (Figure 6).

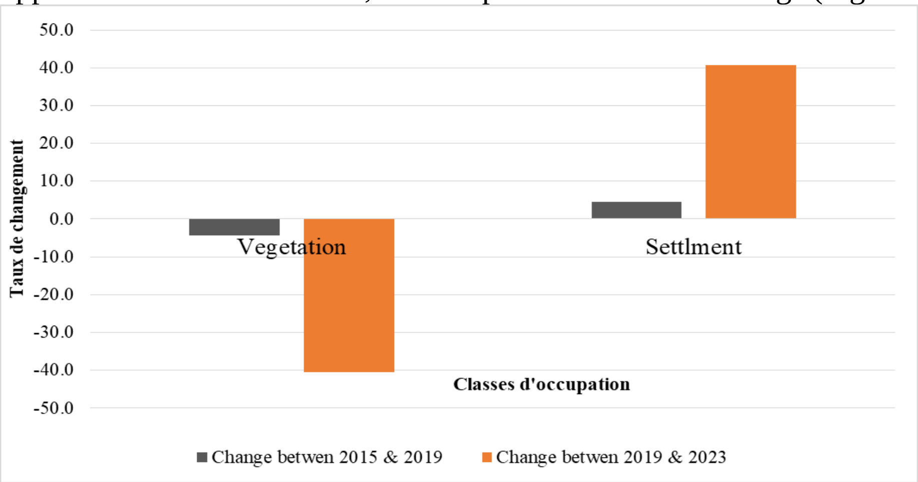

Figure 5: Rate of change in land cover around the town of Kribi, between 2015 and 2023. This rate is calculated from statistics generated from the classification of very high spatial resolution GE images. (Data source: Landsat image processing)

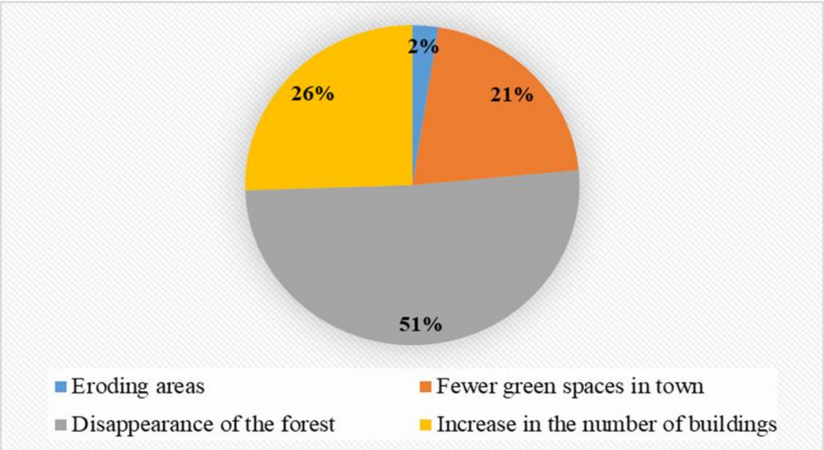

Figure 6: Spatial markers of environmental destruction in the seaside resort of Kribi (Source: field survey, October 2023)

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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 the heat island in the town of Kribi from Landsat 8 images

IV-2-1- Assessment of the heat island situation between 2015 and 2021

Surface temperatures in the seaside town of Kribi have been generated using Landsat 8 and 9 satellite images (bands 10 and 11). Analysis indicates a significant increase in surface temperatures over time and space, with 2017 recorded as an exceptionally hot year. Mapping the spatial distribution of heat islands is a credible approach to visualize this phenomenon (Foissard et al., 2013).

In 2015, surface temperatures in Kribi were relatively mild, with over 75% of the city experiencing temperatures between 19 and 21°C. The average temperature was approximately 26°C, with the hottest area located in the city center, where temperatures reached 31-33°C (Figure 8).

By 2017, there was a dramatic rise in surface temperatures, marked by a significant increase in areas experiencing temperatures between 34 and 36°C (Figure 8). During this year, the average temperature rose to around 28°C.

In 2019, although the extreme heatwave of 2017 had subsided, Kribi remained notably warm, with surface temperatures ranging from 25 to 31°C. The average surface temperature returned to 26°C, yet the town center still recorded the highest temperatures, exceeding 33°C (Figure 8).

Looking ahead to 2023, surface temperatures in Kribi are projected to continue rising, with the average temperature around 28°C. Extreme temperatures (31-35°C) are anticipated across more than 80% of the city, while the lowest temperatures, ranging from 20 to 25°C, are found in the southern part of the city, where vegetation is still prevalent (Figure 7). This increase in temperature is accompanied by significant demographic growth, with the population exceeding 200,000 inhabitants by 2023, and a marked rise in urban development. New districts, such as Dombè, have been subdivided, and infrastructure projects, including the Lolabé-Kribi motorway, have been constructed. These developments have come at the expense of vegetation cover. This period also coincides with the five-year anniversary of the PAK’s operation, resulting in substantial migration to what is now considered the new economic hub of Central Africa.

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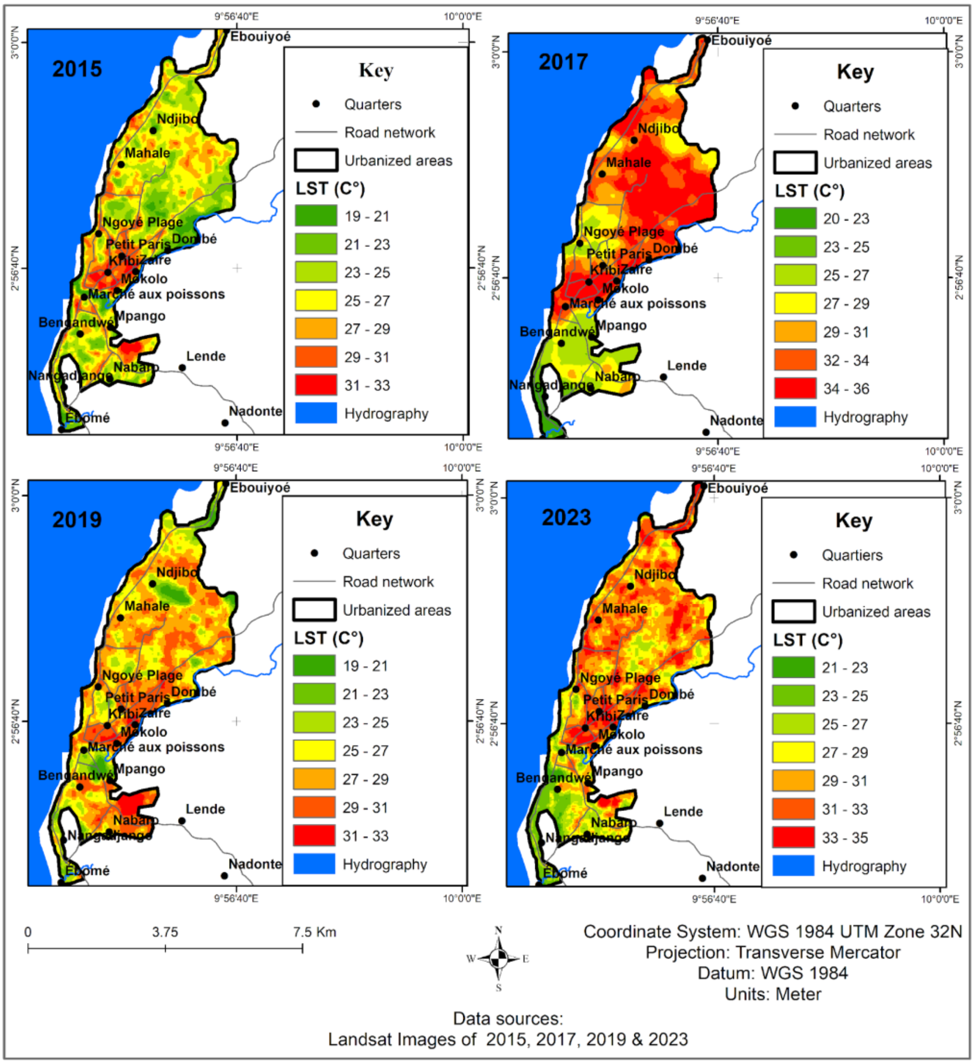

Figure 8: Variation in surface temperatures in the town of Kribi between 2015 and 2023, modelled from bands 10 and 11 of the Landsat 8 sensor
(Data source: Landsat image processing)

Based on field survey data, an overwhelming 98% of residents in Kribi reported experiencing rising temperatures both inside and outside their homes. The primary manifestations of this phenomenon, as perceived by the population, included extreme heat waves (24 respondents), high temperatures (52 respondents), moderate heat (24 respondents), and an extended dry season (42 respondents) (Figure 9).

According to the survey, the hottest period of the day is identified by 40% of respondents as occurring between midday and the afternoon. Additionally, 17% of the population reported feeling hot at all times of the day, while only 6% indicated that the air is cool in the morning (Figure 10).

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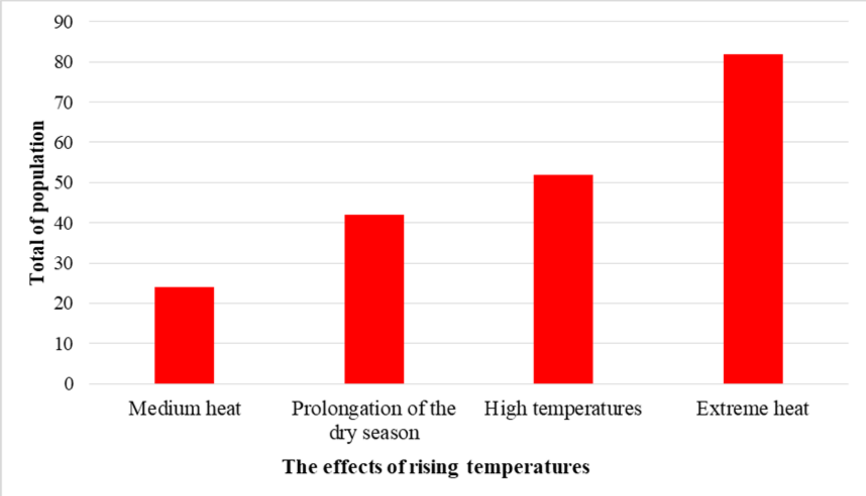

Figure 9: Manifestation of rising temperatures in the town of Kribi
(Data source: field survey of October 2023)

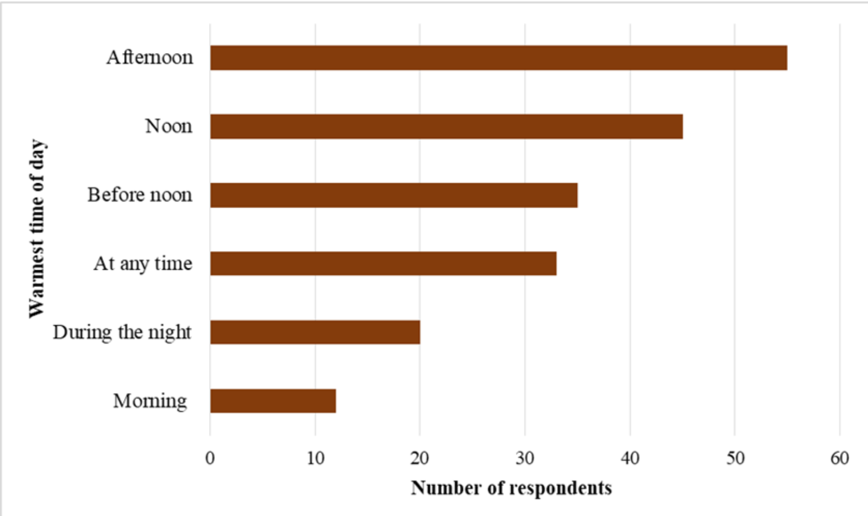

Figure 10: The hottest and least hot moments in the town of Kribi
(Source: October 2023 field survey)

IV-2-2- Prospective analysis of urban heat islands in Kribi over the next 10 years (2033)

A prospective analysis utilizing linear regression and statistical modeling techniques has generated a heat island map for the city of Kribi. The map indicates that, should the current trends in land-use change, building intensification, and population growth persist, Kribi will experience a significant spatial expansion of heat islands by 2023. Specifically, some areas currently classified in the orange zone (31-33°C) are projected to shift to the red zone (33-35°C), while certain green areas (21-27°C) are expected to transition to yellow and orange zones (Figure 7).

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This prospective analysis aligns with the findings of Xiang et al. (2024), who suggest that following initial research on urban heat islands (UHI), there is a critical need for further investigation into the mechanisms underlying heat island intensity (HCI). They advocate for the development of predictive models that could assist in managing the impacts of UHI within urban environments.

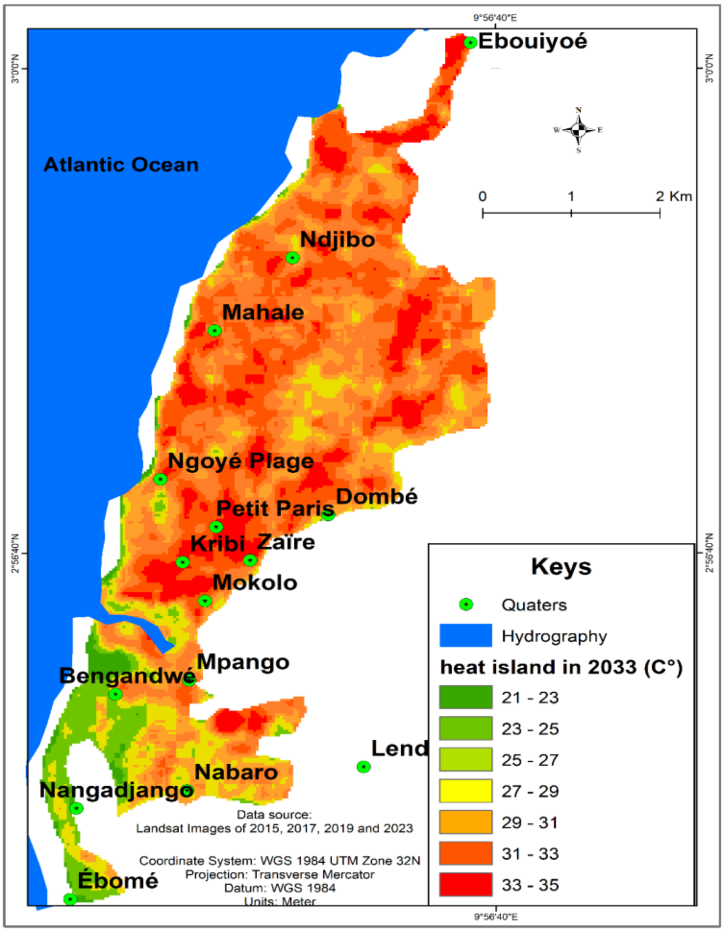

Figure 7: Projected variation in urban heat islands in the city of Kribi in 2033

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) in relation to land use changes has established a significant correlation between the two. Focusing on the urban center, it is evident that in 2015, lower temperatures (19-23°C) predominated, largely due to the extensive presence of vegetation. By 2019, surface temperatures began to rise concurrently with the retreat of vegetation. For instance, districts such as Dombè, which recorded

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surface temperatures between 19-21°C in 2015, experienced an increase to 27-29°C.

By 2023, during a period marked by remarkable spatial expansion in Kribi, vegetation had retreated drastically and irreversibly. Consequently, surface temperatures increased significantly, with very hot zones emerging that recorded temperatures between 33-35°C (Figure 11).

The sealing of soil through the destruction of plant cover, along with the proliferation of buildings and road development, appears to be key factors exacerbating surface temperatures in Kribi. Additionally, this variation in surface temperatures is influenced by the level of sunshine and other climatic factors, which further contribute to the urban heat dynamics in the area.

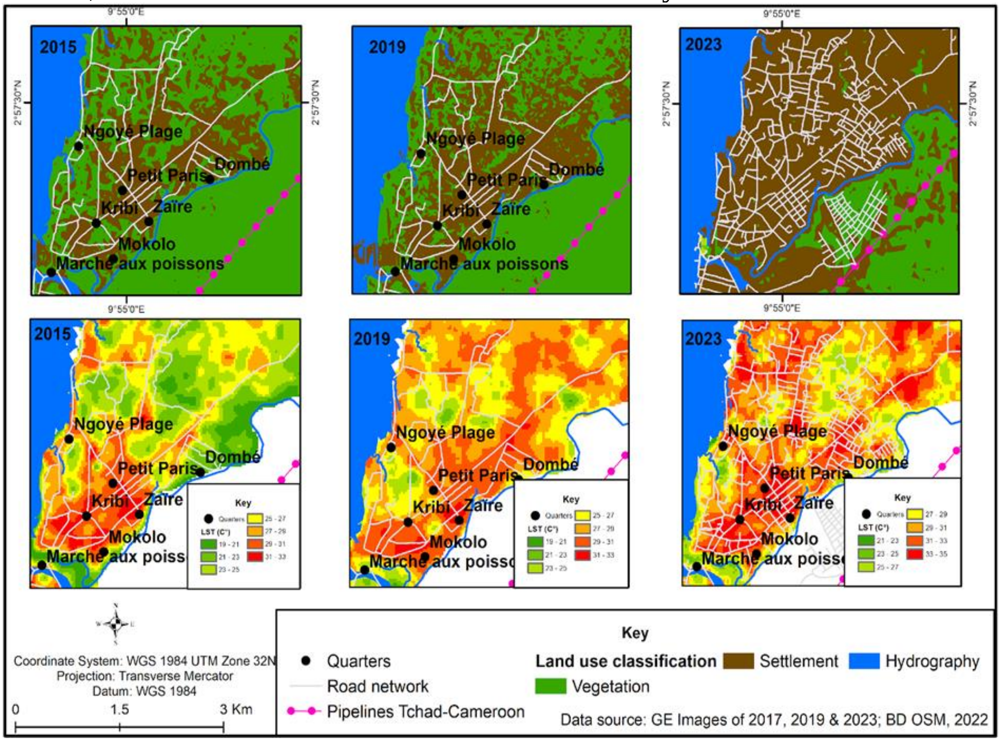

Figure 11: Correlation between changes in land use and changes in surface temperature in the town of Kribi. The data are collected in the Google Earth interface for the land-use classification, and on the USGS site for the Landsat images used to model surface temperatures in the town of Kribi (data source: Landsat image processing)

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

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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 significantly impact the health of urban populations worldwide, rendering them vulnerable to various health issues, as evidenced in the seaside town of Kribi. During field surveys, respondents were asked if they experienced illnesses potentially linked to rising surface temperatures, and more than 10 cases were recorded. The most common ailments included isolation, skin and eye diseases, exhaustion, asthma, and influenza (Figure 12).

Additionally, many residents reported experiencing night sweats, which further disrupt sleep and contribute to overall discomfort. This situation is exacerbated by climate change, with rising temperatures being one of its most pervasive manifestations. The confluence of climate change, the proliferation of heat islands, and associated health impacts is increasingly becoming a pressing reality (Levy, 2016).

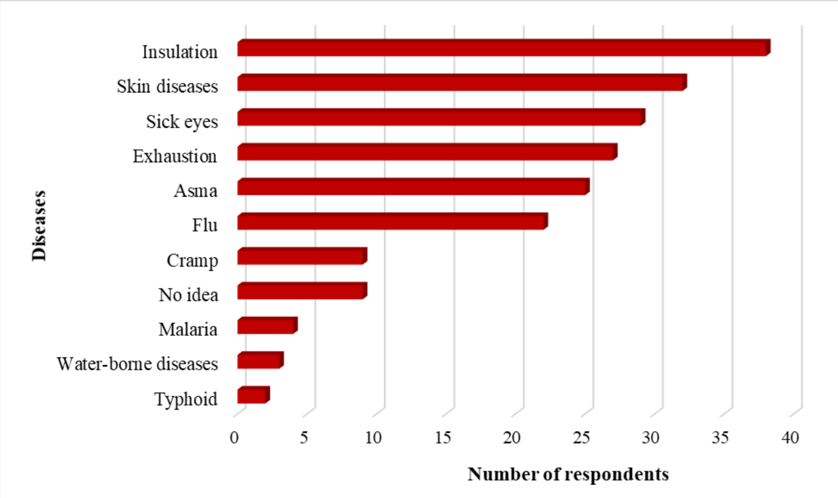

Figure 12: Factors amplifying the vulnerability of Kribi city dwellers to heat islands (Data source: field survey, October 2023)

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

IV-4-2-1- Factors recorded from the perception of city dwellers (collected by questionnaire)

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

However, there are notable sociological spatial inequalities in how these populations experience vulnerability.

Proximity to the Urban Center: Residents living closest to the urban center are the most vulnerable. In contrast, those situated on the periphery experience heat islands differently, as these areas still maintain a higher level of vegetation cover.

Household Composition: Houses inhabited by multiple individuals are also particularly vulnerable. Notably, 47% of respondents reported living in households with 3 to 5 people. This finding aligns with statistics from the Institut National des Statistiques du Cameroun (INS, 2011), which estimates an average of 5.3 individuals per household in urban centers. Single-parent households, or single parents with one child, account for 15%.
When examining the size of living spaces, it becomes evident that many city dwellers reside in cramped conditions. It is common to find more than three individuals sharing a room measuring just 4 by 4 meters. Consequently, this indoor crowding exacerbates the heat experienced in Kribi homes, further contributing to the residents' vulnerability during rising temperatures.

IV-4-2-2- Spatial extension of the Kribi town between 2015 and 2023

The spatial growth of built-up areas in Kribi, as observed through remote sensing, reveals a concerning dynamic in the transformation of the urban landscape, with significant implications for vegetation cover and the emergence of heat islands. Analyses of satellite images, particularly from Landsat, indicate a rapid expansion of urbanized areas, increasing from 310 hectares in 2015 to over 1,373 hectares in 2019, and reaching 2,154 hectares by 2023 (Figure 13).

This rapid urbanization is accompanied by a substantial decline in vegetation cover, which decreased from 5,169 hectares to just 2,516 hectares between 2015 and 2023 (Figure 4). Such loss of vegetation, exacerbated by

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uncontrolled urban development, contributes to rising surface temperatures and fosters the formation of urban heat islands. These heat islands, characterized by elevated temperatures compared to surrounding areas, pose significant risks to public health and the well-being of residents, increasing their vulnerability to heat waves.

In light of these challenges, Qiao et al. (2024) emphasize the necessity for further research to investigate the long-term impacts of urbanization on the local climate and to develop effective adaptation strategies. Similarly, Khan et al. (2024), drawing from the case of Aligarh City, advocate for local decision-makers to promote planning practices that favor sustainability, such as enhancing green spaces and improving water resource management.

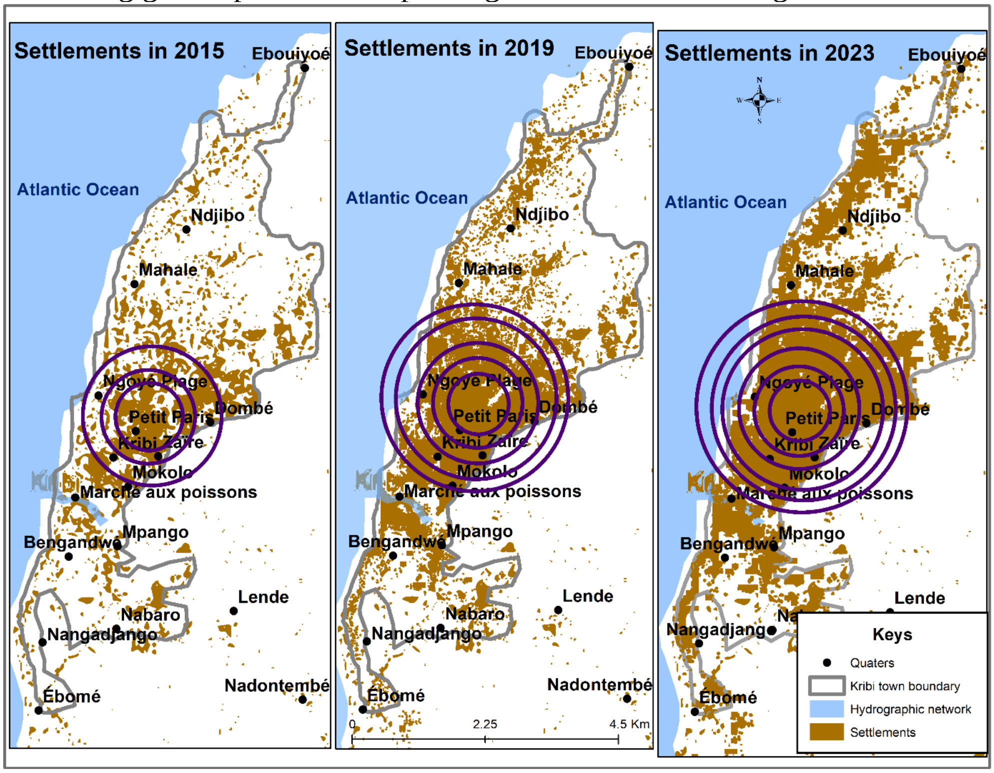

Figure 13: Spatial dynamics of buildings in the city of Kribi between 2015 and 2023

According to Ning et al. (2024), several key factors contribute to the intensification of urban heat islands:

Building Density: Higher densities of buildings tend to accumulate more heat, leading to increased temperatures in urban areas.

Impermeabilized Surfaces: Materials such as concrete and asphalt retain significantly more heat compared to vegetated surfaces, exacerbating heat retention in urban environments.

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Urban Configuration: The layout of streets and buildings plays a crucial role in determining exposure to sunlight and wind, which in turn influences temperature variations across the urban landscape.
These insights underscore the complex interplay of physical factors that drive surface temperature increases in urban settings.

IV-4-2-3- Current and projected demographic growth (1976-2015) and 2035 in the city of Kribi

The availability of data from the three censuses conducted in 1976, 1987, and 2005 provides valuable insights into the rate of population growth in the town of Kribi during the defined intercensal periods: 1976-1987 and 1987-2005.
From 1976 to 1987, the population of Kribi grew at an impressive average annual rate of 6.1%, increasing from 11,261 inhabitants in 1976 to 21,507 by 1987. This growth trajectory continued between 1987 and 2005, with the population expanding at an average annual rate of 5.7%, reaching 59,928 inhabitants by 2005.

Given this demographic trend, projections indicate that by 2015, Kribi is expected to become one of the largest towns in the region, with an estimated population of 104,323 (CAK, 2015) (Figure 14).

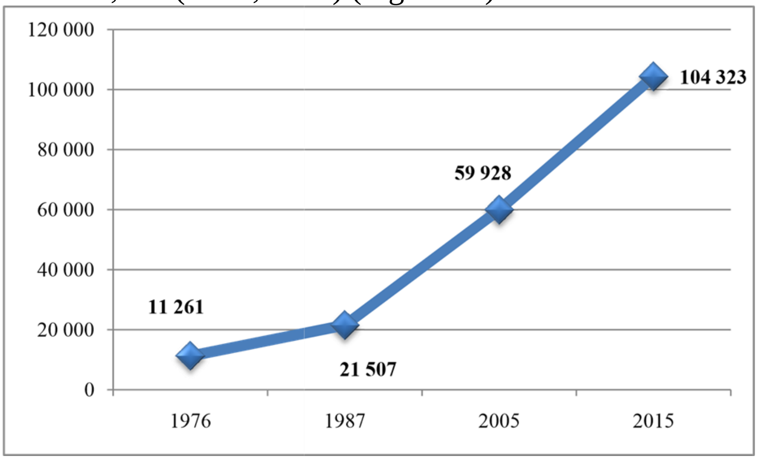

Figure 14: Change in the population of Kribi between 1976 and 2015

A comparative analysis of Kribi's urban growth relative to other towns with populations exceeding 50,000 in 2005 reveals that Kribi is among the few towns that experienced a fourfold increase in population between 1976 and 2005. Examining the intercensal growth rates from the last three censuses, it is evident that Kribi has undergone a remarkable demographic boom. Specifically, between 1976 and 1987, Kribi recorded the 10th highest intercensal growth rate (BUCREP, 1976; 1987; 2005). However, from 1976

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to 2005, it achieved the highest growth rate, comparable to that of Yaoundé and significantly exceeding that of Douala.

If current growth trends persist, Kribi's population is expected to double once again between 2015 and 2030. Projections by the Kribi Urban Community (CUK, 2015) indicate that the population will reach approximately 251,670 by 2035. This estimate reflects a gradual decline in the intercensal growth rate, which has been observed between the censuses of 1976, 1987, and 2005. The gradual decline is extrapolated linearly into future years, supporting the assertion that Kribi became one of the cities with a population of 100,000 by 2015. This projected population growth is expected to occur uniformly across all districts (Figure 15).

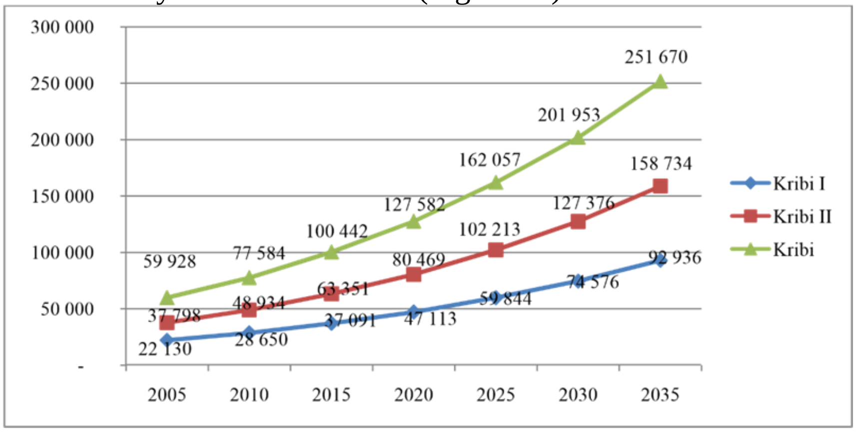

Figure 15: Estimated population of Kribi between 2005 and 2035 based on the average assumption. (Source: CUK, 2015)

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

In response to rising surface temperatures in Kribi, city dwellers are employing various strategies to mitigate the effects 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

Field survey data shows that more than 39% of respondents believed 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% thought 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 16 below.

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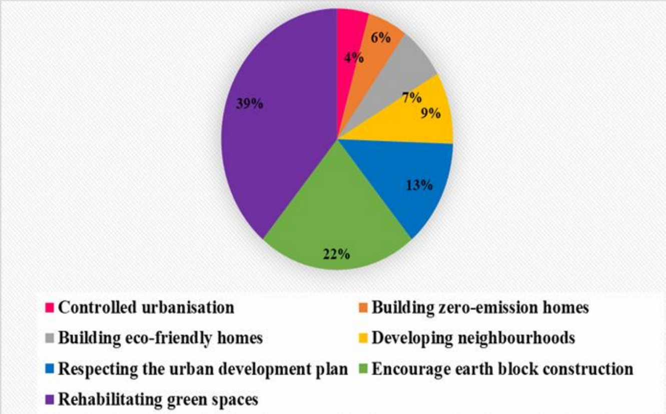

Figure 16: Heat island adaptation strategies that can be implemented in Kribi through political will (Source: field survey, October 2023)

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

The following strategies can be developed by city dwellers to mitigate the perception of surface temperatures both inside and outside their homes. The questions posed to residents aimed to capture the various strategies employed in response to heat. The results reflect the responses of 200 individuals interviewed for the survey.

Based on the survey data, **41%** of respondents indicated that they use air conditioning as a means to alleviate the sensation of heat indoors, a notable percentage for a small town like Kribi. Additionally, **12%** of respondents reported using fans, primarily consisting of average and low-income residents who may not be able to afford the costs associated with air conditioning.

Table 4 summarizes other mitigation efforts, categorizing actions taken both inside and outside the home. This comprehensive approach highlights the diverse strategies residents employ to cope with rising temperatures and enhance their comfort in the face of urban heat challenges.

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%

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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 is closely linked to several key developments, including the construction of the Lolabé-Kribi motorway, which facilitates access to the port via the eastern part of the town, alongside the expansion of agro-industries to the east, growing tourism in the coastal area to the west, and the establishment of the Kribi Autonomous Port (PAK) to the south. These anthropogenic pressures have significantly reduced dense forest cover, declining from 19,400 hectares in 1980 to just 1,470 hectares in 2016, indicating a loss of approximately 220 hectares per year. By 2020, dense forest coverage had virtually disappeared, replaced by secondary forests and plantations.

This trend is corroborated by Landsat/Copernicus images available on Google Earth, which date from 2013 and 2020. These images serve as valuable tools for understanding rapid land-use changes within the context of human activities, environmental interactions, and demographic growth (Hamud et al., 2021). The satellite imagery reveals substantial urban expansion in Kribi towards the north and northeast. Areas that were unoccupied in 2013 have been fully developed by 2020, illustrating significant transformation within just eight years. Furthermore, aside from this planned development, the town

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has also expanded uncontrolled towards the northeast. Kuété & Assongmo (2002) aptly described this phenomenon as development occurring at the expense of the environment along the Kribian coast.

Policies can be applied at two levels:

Sustainable Urban Planning Policy: Kribi could greatly benefit from public policies aimed at promoting sustainable building materials, protecting natural ecosystems, and integrating vegetation into urban projects. Implementing strict regulations on land use would help to curb uncontrolled urban expansion. The work of Rosenzweig et al. (2010) highlights the role of local governments in combating climate change and adapting cities to urban heat islands (UHI), which applies to the context of Kribi.

Community Participation: Engaging local communities in the urban development process presents an effective approach for Kribi. The active involvement of residents is crucial for the success of adaptation strategies. Raising awareness and educating citizens about the importance of vegetation and sustainable practices is vital for building climate resilience. This theme is explored in the article by Bulkeley & Betsill (2005), which examines the role of urban governance in addressing climate challenges and emphasizes the significance of local initiatives.

By implementing these two levels of policy—focused on sustainable urban planning and community engagement—Kribi can enhance its resilience to climate change while fostering a more sustainable urban environment.

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

Urban sprawl, often at the expense of vegetation cover, significantly contributes to changing surface temperatures and the proliferation of heat islands in the city of Kribi. The findings of this research confirm the correlation between these two variables. Notably, the only year that deviated from this trend was 2017. Globally, 2017 is recognized as the year when the average surface temperature exceeded pre-industrial levels by approximately 1.1°C. Furthermore, the average temperature for the period from 2013 to 2017 represents the highest five-year average ever recorded (WMO, 2018). Consequently, Kribi has not been insulated from these global climate trends.

Data from NASA’s satellites illustrate this gradual increase in temperature within Kribi. Between 1982 and 2020, average annual temperatures rose from 25.7°C to 26.5°C, with 2017 marking the hottest year on record (Figure 17). This year was truly exceptional from a climatic perspective, resonating globally and impacting the town of Kribi as well.

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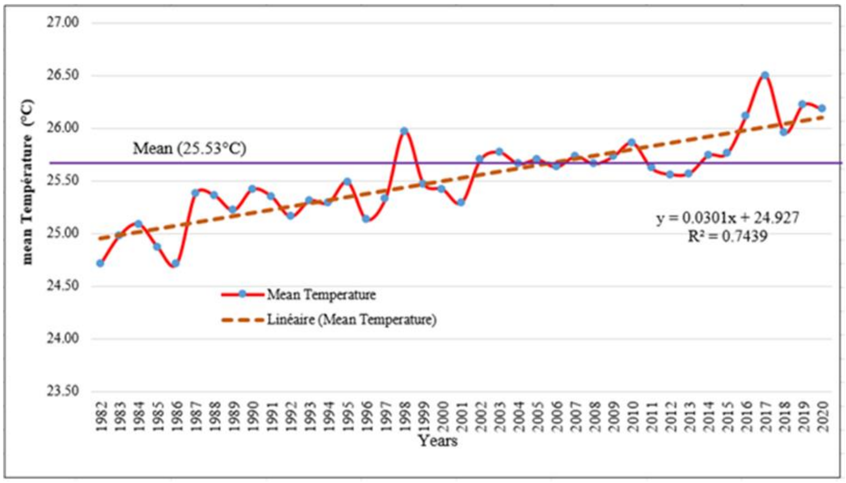

Figure 17: Variation in annual temperatures in the town of Kribi, between 1982 and 2020. Data from NASA satellite

The daily temperature trends for the month indicate a regressive pattern from the first to the last day. The hottest day recorded was the third, with an average temperature of **25.55°C**, while the coolest day was the thirtieth, showing an average temperature of **25.43°C** (Figure 18).

There were several days during the month when temperatures remained relatively stable, particularly from the fourth to the tenth day, and again from the thirteenth to the twentieth day. Beginning from the twentieth day, temperatures began to decline slightly, reaching **25.43°C** by the thirtieth day. However, temperatures experienced a slight uptick to **25.46°C** on the thirty-first day.

Overall, the temperature values showed minimal deviation from the mean, resulting in a standard deviation of **1.10°C**. This indicates a consistent temperature trend throughout the month.

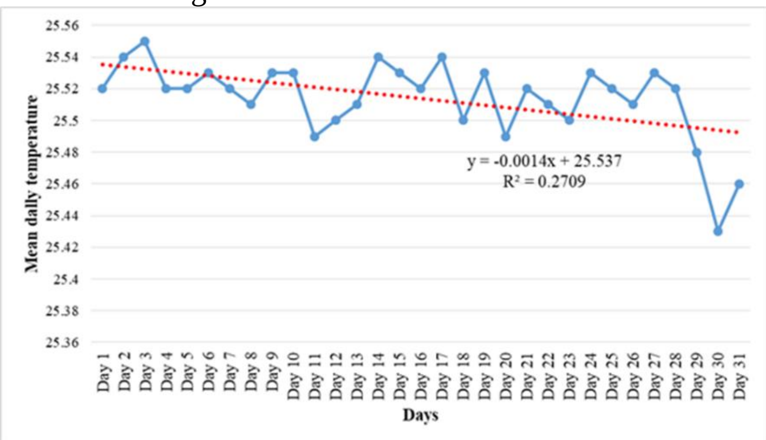

Figure 18: Variation in daily temperatures in the town of Kribi, between 1982 and 2020. Data from NASA satellite

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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 19).

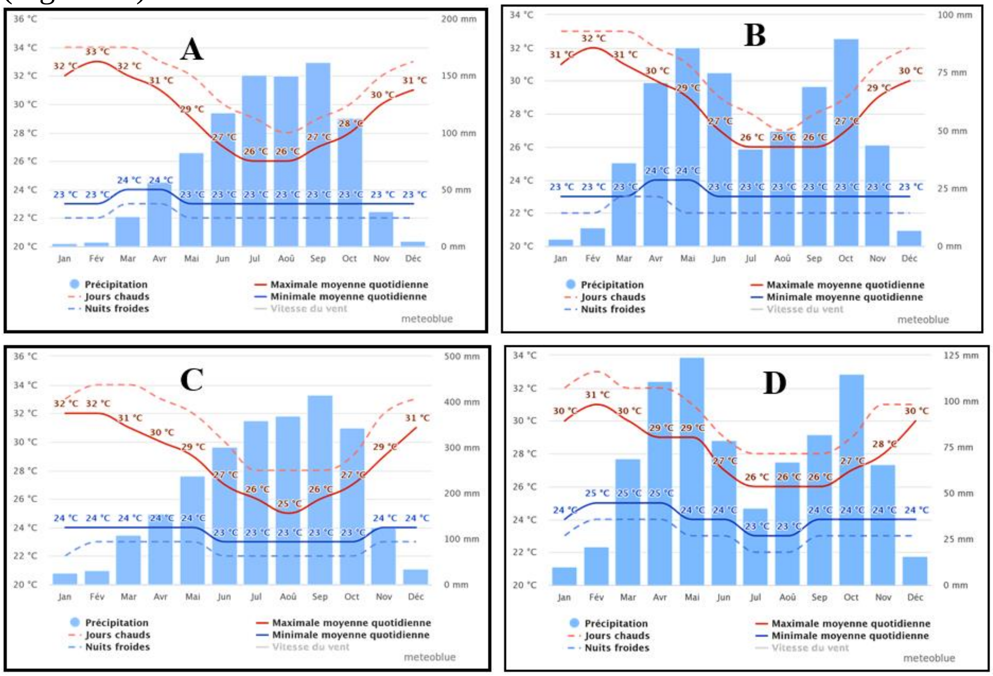

Figure 19: Umbrothermal diagram of four hottest coastal cities. A is the city of Douala; B is Édéa; C is the city of Limbé and D refers to the city of Kribi. The data is provided by the Meteoblue website (https://www.meteoblue.com/fr/meteo/historyclimate/).

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

Urban heat islands (UHIs) present a significant vulnerability for city dwellers, leading to uncomfortable conditions both indoors and outdoors. This issue extends beyond Kribi; on a local scale, UHIs intensify the vulnerability of populations, adversely affecting their health and daily lives. Field surveys conducted in Kribi revealed a concerning prevalence of heat-related illnesses, primarily skin and respiratory diseases. Excessive heat can lead to symptoms such as shortness of breath, weakness, and dry skin, making it a critical thermal risk factor both day and night (Kastendeuch et al., 2023). This situation is especially precarious for the elderly (Bungener, 2004), who are already more susceptible to fatigue and various health issues.

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According to the French Red Cross Foundation (FCRF, 2023), the vulnerability of city dwellers to UHIs has emerged as a pressing public health concern. Ymba (2022) conducted a study that explored the socio-political dimensions of disasters, specifically examining the impacts of UHIs on public health in Côte d'Ivoire. Her epidemiological survey, which included a sample of 1,066 residents in Abidjan, identified the most vulnerable neighborhoods and elucidated the social and health consequences of UHIs for local communities. The results highlighted a clear relationship between high building density, UHI risk, and the health of residents (Satterthwaite, 2007). Major health issues reported included severe migraines, extreme fatigue, dry coughs, dizziness, fainting, and chest pains. These findings closely align with the observations made in Kribi, underscoring a similar pattern of health vulnerabilities linked to urban heat islands.

V-4- Adaptation Strategies against UHI

V-4-1- A Reliance on Air Conditioning

This study concludes that the widespread use of air conditioning as an adaptation strategy to urban heat islands (UHIs) in Kribi is directly linked to rising surface temperatures and the proliferation of heat islands. Addressing the vulnerability of city dwellers to UHIs is crucial (Haouès-Jouve & Hidalgo, 2014). Air conditioning serves as an effective solution, providing residents with comfortable and cool indoor environments, which is essential when ambient temperatures soar to around 35°C in Kribi.

Low-income residents often rely on fans for relief, while the poorest households may resort to simply ventilating their homes and minimizing heat-generating activities indoors. Outside their homes, however, Kribi residents face significant challenges in combating UHIs, frequently enduring intense heat during their daily activities.

Maillard et al. (2014) suggest a potential solution involving the humidification of pavements in large cities, using Lyon, France, as a successful example. As global temperatures continue to rise (Wyard et al., 2018), coastal towns like Kribi are increasingly vulnerable.

Air conditioning consumption in Kribi is predominantly driven by the tertiary sector, which accounts for 71% of total usage. This trend mirrors findings from France, where the tertiary sector accounted for 80% of air conditioning use in 2003 (Gaz de France, 2003). In 2000, approximately 20% of this demand stemmed from indoor activities such as computer rooms and laboratories, rising to 30% by 2018, according to the French Environment and Energy Management Agency (ADEME, 2018). A Europe-wide study forecasts substantial electricity consumption (exceeding 10 exajoules) linked to air conditioning use (Abergel & Jordan, 2019). This excessive reliance on

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air conditioning presents challenges not only for individual households but also for the broader environment.

The following section will explore the limitations associated with air conditioning use and discuss prospects for mitigating heat islands within the framework of the Millennium Development Goals (MDGs).

V-4-2- A nature based solution

An increase in green spaces in the town of Kribi is a commendable development. One of the most effective solutions for reducing urban heat islands (UHIs) is to enhance vegetation in urban areas, as demonstrated in the Arabian Gulf (King et al., 2024). In Kribi, initiatives such as planting trees, protecting mangroves, and creating urban parks could significantly mitigate the effects of UHI. This importance of green infrastructure for adapting cities to climate change and urban heat is further emphasized by Gill et al. (2007). Their findings suggest that the model they present is applicable not only to Kribi but also to many other African cities.

Additionally, the adoption of reflective building materials represents an innovative approach to clean urban development. Utilizing materials that reflect solar heat—such as white roofs and appropriate road surfaces—could further help reduce temperatures in urbanized areas. Santamouris (2015) explores various strategies for mitigating UHI, including both technological innovations and nature-based solutions.

Effective stormwater management is another critical strategy for mitigating UHI. Implementing good stormwater practices, such as the creation of retention basins, can help cool the ambient air in highly urbanized areas like Kribi.

Fu et al. (2024) discuss the uncertainties associated with estimating the UHI effect based on different reference delineation methods, particularly those that differentiate between urban and rural areas and utilize local climate zones (LCZs). They identify several sources of uncertainty in UHI estimates, including (i) Variability in temperature and land cover data. (ii) Potential biases in classifying urban and rural areas. (iii) Differences in data collection methods, such as remote sensing and weather stations.

Addressing these uncertainties is crucial for accurately assessing and managing the impacts of UHIs in Kribi and similar urban environments.

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

The first constraint affecting urban development and comfort in Kribi is energy (Fondja Wandji, 2011). The State of Cameroon faces significant challenges in meeting household electricity demand due to supply shortages, leading to frequent and prolonged power outages. In Kribi, residents experience at least 2 to 3 power cuts daily, particularly during the dry season

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when river flows decrease, limiting electricity generation. The privatization of the electricity production company is viewed by many as a violation of consumer rights (Etogo Nyaga, 2020). Current management by ENEO has drawn widespread criticism from the public, not only for the frequency of power cuts but also for the poor condition of power transmission infrastructure, which falls under the purview of the national electricity transmission company (SONATREL). In this context, increasing the number of air conditioners in homes and businesses is seen as impractical.

The second constraint is environmental, particularly concerning indoor conditions. Water waste and greenhouse gas emissions represent significant sources of pollution that deteriorate indoor comfort in both residential and hotel buildings (Dalel & Ammar, undated; Tahar, Guermit, 2019). The challenge of cooling indoor spaces further complicates this issue, as reliance on air conditioning can exacerbate energy shortages and environmental degradation. Addressing these constraints is crucial for improving the overall living conditions in Kribi.

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.

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V-6-2- Outside Buildings

Promoting urban ecology through the creation of green spaces appears to be an effective strategy for combating urban heat islands (UHIs) in Kribi. The city requires initiatives to green its environment, establishing outdoor refuge areas where residents can enjoy improved comfort (Molina et al., 2023). Such green spaces would enable residents to experience a refreshing urban atmosphere (Ameglio Ngao & Saudreau, 2019). Urban vegetation serves as a means of cooling, mitigating UHIs, and preventing heat waves (Lamine, 2023; Lauffenburger, 2010).

Raymond and Simon (2012) support this notion, arguing that urban history has consistently demonstrated a coexistence of urban and ecological elements. They assert that nature has always been a part of cities, regardless of the intentions of urban planners or residents. Scholars like Saint Laurent (2002), Saint-Arnaud (2008), and De Vreese (2019) compare these patches of vegetation to "urban islands," drawing from the biogeographical island theory developed by Robert MacArthur and Edward O. Wilson. Clergeau recently applied this theory to urban contexts, suggesting that these isolated green spaces function as islands subject to similar patterns of dispersion and biological exchange as vegetation on oceanic islands.

Landolt (2001) makes a comparable observation regarding Zurich, which hosts over 1,211 plant species—nearly double the number found in an equivalent area of the Swiss plateau. A recent study conducted in Douala, Cameroon's economic capital, reinforces the need for open spaces in this densely populated city of over 4 million inhabitants, which suffers under the burden of heat islands (Mahguoh, 2022). Creating these green areas is essential for enhancing ventilation and comfort.

These efforts align with the Millennium Development Goals (MDGs) 11 and 13, which advocate for sustainable cities and communities as well as action against climate change, respectively. By prioritizing urban ecology, Kribi can work towards a more livable and resilient urban environment.

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 (Harlan, S, & Ruddell, (2011). These are the same recommendations we have arrived at in this study, based on local perceptions recorded by the questionnaire.

V-7- Considerations specific to Kribi: coastal vulnerability and double exposure

Kribi is particularly vulnerable to rising sea levels, which poses a significant threat alongside urban heat islands (UHIs). The threat of sea-level rise exacerbates the risks of flooding and submersion in low-lying areas,

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creating a dual climate vulnerability that necessitates integrated adaptation strategies. The research by Neumann et al. (2015) offers a global assessment of the vulnerability of coastal populations, applicable to Kribi. Similarly, Dasgupta et al. (2009) analyze the impacts of sea-level rise in developing countries, providing insights that are relevant for Kribi (Fongnzssié et al., 2018).

Additionally, the loss of mangroves and coastal ecosystems represents a serious challenge that affects the local climate in Kribi (Moudingo et al., 2020). Mangroves are vital for regulating the climate, protecting against flooding, and preventing coastal erosion. The destruction of these ecosystems for infrastructure development could worsen the effects of urban heat islands and expose the city to heightened climate risks. Previous studies, such as those conducted by Fongnzossié et al. (2018), have documented the degradation of mangrove ecosystems in the Kribi area and its detrimental impact on the local climate.

To address these intertwined challenges, Kribi must implement comprehensive and sustainable strategies that protect both its coastal ecosystems and urban environments.

Conclusion

This study on urban heat islands has examined the interplay between changes in land use and the rise of heat islands, exacerbated by climate change, and how these factors contribute to the vulnerability of urban dwellers in the Cameroonian coastal and port city of Kribi. Notably, changes in land use are identified as the primary cause of the increasing prevalence of heat islands.

The decline of green space in Kribi has been drastic, dropping from 5,169 hectares (83%) in 2015 to 2,516 hectares (43%) by 2023, resulting in a loss of 2,653 hectares. This reduction was particularly evident between 2015 and 2019 when green space decreased from 4,908 hectares (83%) to 2,516 hectares (43%). In certain areas of Kribi, temperatures can soar to 35°C, while the southern part of the town experiences lower temperatures around 21°C. Projections for the next decade suggest an increase in heat poles within the city, although overall temperature values are expected to remain relatively stable.

Urban residents are particularly susceptible to these rising surface temperatures, as evidenced by the prevalence of respiratory and skin diseases. In response to these challenges, city dwellers have adopted various adaptation strategies, both inside and outside their homes. Among these strategies, air conditioning has the highest adoption rate, with 41% of respondents reporting its use. Other common strategies include using fans, opening shutters, and limiting heat-generating activities indoors.

Given the extensive reliance on air conditioning, further investigation is warranted to understand the stakeholders involved, the most commonly used brands, and the neighborhoods with the highest usage rates. Such an investigation would help establish a clearer connection between changes in land use, rising surface temperatures, and air conditioning usage in Kribi. This understanding is crucial for developing effective adaptation strategies and promoting sustainable urban planning in the face of escalating climate challenges.

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