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Urban heat island modeling and socio-economic vulnerability assessment in Yaoundé, Central Africa

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ABSTRACT

Cities in Central Africa, especially Yaoundé in Cameroon, are experiencing rising temperatures, which is a pressing environmental issue. This article examines urban heat islands (UHIs) and the socio-economic vulnerability of residents from 2015 to 2030. It finds that heatwaves are becoming more frequent and intense, posing health risks to the population. Using satellite data, surveys of 300 households, and field observations, researchers discovered that surface temperatures have increased from 24–31°C in 2015 to a projected 38°C by 2030. The area covered by hard surfaces has also grown significantly, from 24,911.6 hectares to an expected 132,815.4 hectares. Notably, 91% of households reported feeling the heat rise, revealing varying levels of vulnerability. Approximately 45.5% of families earn between 50,000 and 100,000 XAF (approximately 76 to 152 euros) per month, which limits their ability to adapt to extreme weather conditions. Health issues reported include headaches, fatigue, insomnia, and respiratory problems. The study recommends targeted solutions to help residents adapt to UHIs, emphasizing the need for improved urban infrastructure and support for vulnerable communities. In conclusion, it stresses the urgent need for concrete actions to mitigate UHI impacts in Yaoundé and address the socio-economic disparities affecting household vulnerability, ultimately aiming for a healthier and more resilient urban environment.

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1. Introduction

Urban heat islands (UHIs) occur in urban areas where impermeable surfaces absorb heat, resulting in higher temperatures than in surrounding rural areas (Ullah et al. 2023; Amir Siddique et al. 2021). This temperature disparity adversely affects public health, environmental quality, and economic stability.

In Central Africa, rapid urbanization is a significant factor, with urban growth projected to rise from 33% in 1990 to 60% by 2050 (Brockhoff 1998). Cities like Yaoundé exemplify this trend, with a population expected to reach 5 million by 2035 (Bocquier 2005), intensifying the UHI effect. The replacement of natural surfaces with impermeable materials diminishes essential green spaces (Le Mentec 2022), worsening living conditions, particularly for vulnerable communities (Li et al. 2021; Khaled et al. 2023).

Inadequate urban planning restricts green space development and increases socio-economic vulnerability, particularly for low-income populations in overcrowded areas (Lemonsu et al. 2015; Leal Filho et al. 2018). Limited access to support exacerbates the impacts of urbanization on these communities (Sabrin et al. 2020).

This research addresses the urgent issue of UHI formation in African cities, focusing on Yaoundé. The study aims to model UHIs and assess their correlation with socio-economic vulnerability using remote sensing data (Almeida et al. 2021) and statistical analyses, clarifying the factors contributing to UHI dynamics and their implications for urban climate (Anjos et al. 2025; Pratama et al. 2025).

Despite extensive research on urban heat islands (UHIs) in major global cities, Central African cities remain understudied. Most existing studies focus on demographic changes and urbanization, with few addressing the joint impact of UHI evolution on socio-economic vulnerability. This gap limits our understanding of how socio-economic and spatial inequalities affect the vulnerability of urban populations to heat.

This study aims to answer key questions: What are the spatiotemporal dynamics of UHIs in Yaoundé from 2015 to 2030? How do socio-spatial factors influence household vulnerability to UHIs? What lessons can inform equitable urban governance and climate justice in African cities?

The objective is to model UHIs in Yaoundé and characterize the resulting vulnerability of populations.

This involves assessing the extent and spatial distribution of UHIs, examining how geographical and economic factors influence vulnerability, and exploring adaptation strategies.

To achieve this, the research uses the IPCC (2013) framework for vulnerability analysis based on exposure, sensitivity, and adaptation. An integrated approach combining remote sensing data (Almeida et al. 2021) and statistical analyses will clarify the factors contributing to UHIs and their impacts on the local urban climate (Anjos et al. 2025; Pratama et al. 2025).

2. Theoretical framework and public policy applying to UHI and socio-economic vulnerability formation of urban heat islands (UHIs)

Urban heat islands (UHIs) are urban areas with higher temperatures than surrounding rural regions, caused by impermeable surfaces, high building density, and a lack of vegetation. Introduced by Howard in 1898 and further explored by Oke in 1973, Foissard (2015) connected UHIs to climate change, particularly in Rennes. Vulnerability to UHIs is influenced by socio-economic factors, such as low income and limited resources, with elderly or ill individuals at greater risk. The environmental justice framework, initiated by Bullard (1990) in *Dumping in Dixie*, highlights inequalities in environmental burdens, showing that low-income communities are disproportionately affected by UHIs (Bryant and Mohai 1992; Rey et al. 2009). Mitigation strategies must reduce socio-economic vulnerability, with concepts of resilience and adaptation from Holling (1973) being essential. Smit and Carter et al. (2015) emphasize the importance of sustainable urban planning, increasing green spaces, and improving access to resources and health services. African public policy documents reflect a commitment to addressing climate challenges and achieving equitable urban environments.

3. Geographical settings and administrative situation of Yaoundé

Yaoundé, the capital of Cameroon, is located at an altitude of 750 m and receives an average annual rainfall of 1,609.57 mm, with a mean temperature of 23.02°C. Low wind speeds of about 4 m/s during the dry season hinder pollutant dispersion and worsen urban heat islands (Matcheubou et al. 2009). The city's undulating topography affects water flow, making some areas particularly prone to flooding (Tchindjang et al. 2012, 2005).

Rapid urbanization has transformed the landscape (Figure 1), expanding from 15 km² in 1956 to 310 km² in 2010, while the population grew from 1,817,524 in 2005 to 2,765,568 in 2015 (BUCREP 2010). This growth

increases the city's vulnerability to natural disasters, especially in areas like Soa, Obala, Nkolafamba, Mbankomo, and Okola. Housing inequalities also complicate the situation, as planned neighborhoods are typically less affected by heat than informal settlements (Bopda 1997; Durang 2003; Ojuku et al. 2022).

4. Tools and methods

The methodological approach adopted in this study is holistic, combining geomatics and social science perspectives. A geomatics approach utilizes remote sensing data to quantify and spatialize urban heat islands (UHIs) and analyze urban sprawl. Complementing this is a social science approach, which involves questionnaire-based field surveys administered to households in Yaoundé. This survey aims to gather insights into residents' experiences with UHIs and their levels of vulnerability.

4.1. Data collection

4.1.1. Remote sensing data collection and processing

The images processed for this research are Landsat 8 & 9. This sensor produces thermal data, recorded in bands 10&11. These bands have a spatial resolution of 100 m. We resampled using the multispectral Sentinel image at 10 m. Table 1 below shows the characteristics of these images.

To model surface temperatures and quantify urban heat islands (UHIs), we used the RS&GIS plugin in QGIS. We first installed the plugin and prepared the Landsat 8 and 9 thermal images, ensuring proper georeferencing. Then, we imported the georeferenced image using the 'Add a Layer' tool and selected the thermal bands (bands 10 and 11). Finally, we applied the conversion formula from the plugin to calculate the surface temperature (USGS 2020).

$$T = (DN * R) + B \text{ soit } T = (B10 * 0,00341802) + 149,0 \quad (1)$$

Where:

- T is the surface temperature in Kelvin (K) or degrees Celsius (°C);
- DN is the numerical value of the thermal band (Digital Number);
- R is the Radiometric Conversion Factor;
- B is the Bias Value.

The values of RR and BB are specific to each type of satellite data and can be found in the official documentation provided by the data supplier. In this instance, the formula is derived from official NASA documentation (Wukelic et al. 1989).

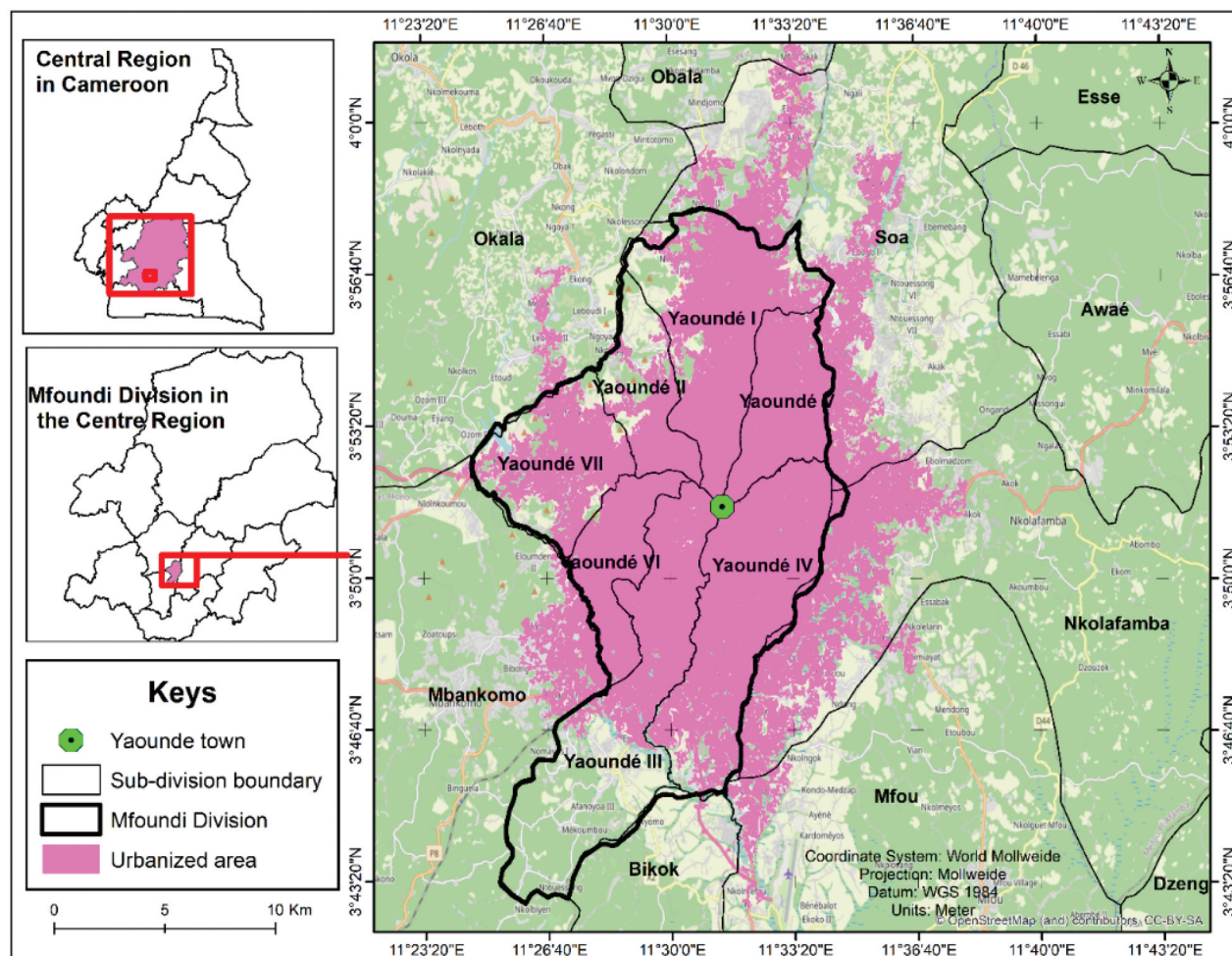


Figure 1. Study area location map. Data source: OSM geodatabase, and administrative limits of the division and sub-division of Cameroon, designed by the authors.

Table 1. Characteristics of processed satellite images.

Data	Season	Pick-up time	Path & Row	Sensors	Initial Spatial resolution	Spatial resolution Resampling	Bands	Purpose
2015–03–25	Dryer	09:32:33	185 057	LC08	100 m	10 m	10&11	LST
2020–03–23	Dryer	11:23:00	185 057	LC008	100 m	10 m	10&11	LST
2025–12–21	Dryer	09:26:55	184 057	LC09	100 m	10 m	10&11	LST

Following this, we proceeded with calculating the surface temperature using the RS&GIS plugin, applying the conversion formula to the entire image. Once the calculations were complete, we visualized the results, extracted the area of interest, and performed map dressing to enhance the data's presentation.

4.1.2. Socio-economic data collection and processing

To assess Yaoundé's vulnerability to extreme heat, a survey was conducted in February 2025 among 300 heads of household across twenty-six neighborhoods using stratified random sampling, targeting twelve households per neighborhood based on factors like time spent in the area and air conditioning availability (Table 2). Data was organized by neighborhood, focusing on densely populated areas such as Mvog-ada, Anguissa, and Obili, where green space is limited.

The survey included three sections: demographic and socio-economic characteristics (notably, the majority were aged 25 to 35 years), land use and heat perceptions, and the relationship between perceived heat island effects, income, and health outcomes. The sample comprised 160 women and 140 men, representing 53% and 47%, respectively.

4.2. Statistical modeling

4.2.1. Method for prospective analysis of surface temperatures in the city of Yaoundé

For a prospective analysis of surface temperatures from Landsat 8 & 9 satellite data, we used a statistical modelling or numerical simulation approach, taking inspiration from IPCC (2013), which believes that future climate change can be projected using global or regional climate models.

Table 2. Age groups of surveyed populations in Yaoundé and duration of residence of surveyed populations in Yaoundé.

Age groups	Effectif	Percentage (%)
25 à 35 years	134	45
36 à 45 years	70	23
46 à 55 years	51	17
56 à 65 years	12	4
Plus de 65 years	33	11
Grand total	300	100
Duration of Residence in the City of Yaoundé	Effectifs	Percentage (%)
2 à 5ans	53	18
5 à 10 ans	23	8
10 à 15 ans	85	28
15 à 20 ans	51	17
20 à 25 ans	42	14
Plus de 25 ans	46	15
Grand total	300	100

The mathematical formula used to project future surface temperatures in the city of Yaoundé, Cameroon, is as follows:

$$T(t) = T_0 + 1 + \beta \cdot (t - t_0) + \varepsilon(t) \quad (2)$$

Where:

- $T(t)$ is the projected surface temperature at time t ;
- T_0 is the initial surface temperature at time t_0 ;
- β is the rate of change of surface temperature per unit time, which can be estimated using statistical methods such as linear regression (Nakicenovic 2000);
- $\varepsilon(t)$ is an error term representing uncertainties and variabilities in the projections.

This model relies on four main assumptions: (i) Linearity: The relationship between time t and temperature $T(t)$ is linear, indicating constant temperature variations. (ii) Independence of Errors: The error terms $\varepsilon(t)$ are independent, suggesting no systematic bias in measurements. (iii) Normality of Errors: The errors $\varepsilon(t)$ follow a normal distribution, allowing standard statistical estimation. (iv) Homoscedasticity: The variances of the errors remain constant over time, indicating stable dispersion.

However, the model has limitations. With only three data points (2015, 2020, 2025), capturing long-term trends is challenging, restricting the analysis to five years up to 2030. Additionally, potential non-linear climatic behaviors and external factors – such as political changes or natural disasters – are not accounted for (Wang et al. 2025).

Parameter interpretation may also be biased if the data isn't representative, distorting predictions. While the linear model can provide useful approximations, results should be interpreted cautiously, particularly for future forecasts. As Van Vuuren et al. (2011) note, uncertainties in future temperature projections can be

better assessed using numerical simulation methods, which we will employ to quantify these uncertainties.

$$\sigma^2 = (\Delta T * \sigma^2 T) + (\Delta t^2 * \sigma^2 t) \quad (3)$$

Where:

- σ^2 is the variance of the uncertainty;
- ΔT is the variation in surface temperature;
- $\sigma^2 T$ is the variance of surface temperature;
- Δt is the variation in time;
- $\sigma^2 t$ is the variance of time.

This formula is based on the theory of uncertainty propagation (Saltelli 2000) and is used to assess uncertainties in future surface temperature projections. For short-term projections (≥ 50 years), this uncertainty ranges from +or -0.5°C to 1.5°C (IPCC 2013). We found an uncertainty of 0.612°C for the city of Yaoundé.

4.2.2. A method for prospective analysis of land use in the city of Yaoundé

The input data for the model consists of Landsat images from 2015, 2020, and 2025. These datasets have enabled the production of a land use dynamics map, which will serve as a reference for the projection. Occupancy is projected using the Markov model in IDRISI Selva (Brown et al. 2000; Turner 1987). A 2030 projection of land cover is thus produced to give an idea of future trends and help decision-makers make forecasts. The equation, inspired by Baker (1989), is as follows:

$$nt + 1 = DP [f(t, x)] \quad nt \quad (4)$$

And

$$p_{ij} = f(t, x) = b_1 X_1 + b_2 X_2 + \dots + b_s X_s \quad p_{ij} \\ = f(t, x) = b_1 X_1 + b_2 X_2 + \dots + b_s X_s \quad (5)$$

Where:

p_{ij} are the elements of the transition probability matrix P , and the parameters of the transition probability matrix.

To construct a transition probability matrix from this equation, we first defined the states at three time points (2015, 2020, and 2025). We then calculated the transition probabilities for each pair of states (i, j) using the equation $p_{ij} = f(t, x)$ to compute the transition probability. This involves plugging in the appropriate values for the predictors $X_1, X_2, \dots, X_s$. Finally, we built the matrix.

As a validation measure, we utilized the confusion matrix for each year. This matrix provides a visual representation of the model's performance by comparing predictions to true labels, allowing us to identify the types of errors made. This leads to the calculation of the Kappa index (Tables 3–5).

Table 3. Matrice de confusion et indice de Kappa pour l'année 2015.

Data	Dense forest	Hydrography	Dense building	Less dens building	Degraded forest	Row Total	Kappa index	Results
Dense forest	8392	17	8	0	0	8417	PMC	975
Hydrography	60	1721	20	57	0	1858	PBC	60745
Dense building	98	5	4477	230	0	4810	PBC-PMC	59770
Less dens building	21	6	462	1745	8	2242	PBC-PMC/PBC*100	98.3
Degraded forest	0	0	0	0	43418	43418		
Column Total	8571	1749	4967	2032	43426	60745		

Table 4. Matrice de confusion et indice de Kappa pour l'année 2020.

Data	Dense forest	Hydrography	Dense building	Less dens building	Degraded forest	Row Total	Kappa index	Results
Dense forest	6898	16	91	5	0	7010	PMC	2020
Hydrography	93	2133	4	57	48	2335	PBC	68606
Dense building	306	1	2742	187	0	3236	PBC-PMC	66586
Less dense building	6	213	993	2111	0	3323	PBC-PMC/PBC*100	97.05
Degraded forest	0	0	0	0	52702	52702		
Column Total	7303	2363	3830	2360	52750	68606		

Table 5. Matrice de confusion et indice de Kappa pour l'année 2025.

Data	Dense forest	Hydrography	Dense building	Less dens building	Degraded forest	Row Total	Kappa index	Results
Dense forest	7420	25	12	1	0	7458	PMC	980
Hydrography	80	1600	30	40	0	1750	PBC	60000
Dense building	120	10	4000	250	0	4380	PBC-PMC	59000
Less dens building	30	8	500	1800	5	2343	PBC-PMC/PBC*100	97.5
Degraded forest	0	0	0	0	42000	42000		
Column Total	7650	1643	4542	2091	42005	57931		

4.3. Analysis of field survey data

Two types of analyses were employed to process the collected data: a univariate analysis to describe and present the study variables, and a bivariate analysis to explore the relationships among these variables. The statistical methods utilized included simple linear regression and Spearman's correlation coefficient, which facilitated a deeper understanding and quantification of the connections between household characteristics and vulnerability to heat islands. All survey data were entered into Excel 2013, with subsequent analyses conducted using SPSS Statistics software.

5. Results

The urban heat island effect is characterized by elevated temperatures in urban areas compared to their surroundings. This phenomenon arises from a mix of natural and human factors, particularly the heat generated by dense built environments replacing forests and the concentration of greenhouse gas-emitting activities. The city's diverse surfaces that absorb and retain energy further contribute to this effect. Field surveys among households in Yaoundé have provided valuable insights into this context.

5.1. Exposition aux ICH dans la ville de Yaoundé

5.1.1. Mapping urban heat islands in Yaoundé

Maps illustrating the spatial distribution of urban heat islands (UHIs) in Yaoundé for 2015, 2020, and 2025

show a significant rise in surface temperatures in densely built-up areas, with red zones indicating the most pronounced effects of urbanization. In 2015, surface temperatures ranged from 24°C to 31°C, particularly in urbanized regions, while the outskirts displayed similar temperatures of 27°C to 28°C. By 2020, temperatures increased to 25°C to 33°C, highlighting intensified heat islands and evident urban sprawl, especially to the north and south of the city. Projections for 2025 indicate temperatures rising to 26°C to 35°C, with high heat concentrations expanding toward the periphery, closely following major traffic arteries (Figure 2). The Yaoundé-Nsimalen free-way has notably contributed to vegetation loss and urban sprawl. The maps also reflect the road network's impact, as both main and secondary roads elevate temperatures due to traffic and heat emissions. Looking ahead to 2030, UHIs are expected to become even more pronounced, with temperatures potentially reaching 38°C in the urban core, contributing to a perception of suffocation among residents, as revealed through questionnaire analysis.

Thermal data analysis in Yaoundé shows notable differences in urban heat, especially in relation to the city center's socio-economic infrastructure. Over 80% of Yaoundé 5 is in very hot zones, followed by Yaoundé 4 (78%), Yaoundé 1 (75%), and Yaoundé 3 (72%), highlighting increased vulnerability.

Urban congestion (Figure 3) in the city center exacerbates heat, negatively affecting residents' well-being. Peripheral areas, often with inadequate infrastructure, struggle to cope with the heat.

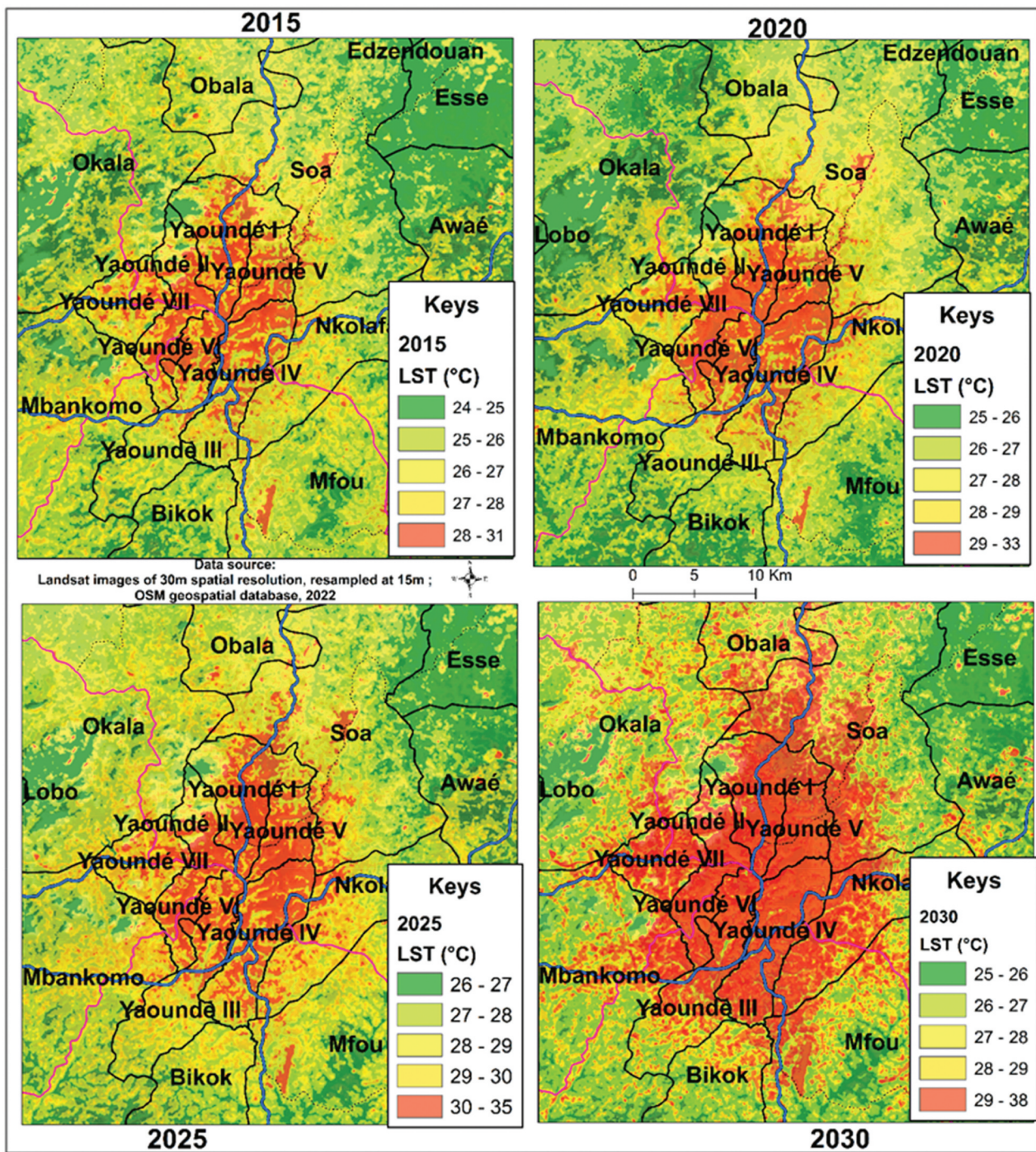


Figure 2. Spatio-temporal dynamics of urban heat islands in the city of Yaoundé, between 2015 and 2025, with a projection to 20,230. Data source: landsat 8&9 images from 2015, 2020 and 2025.

To address this, it's crucial to develop infrastructure in peripheral regions, create green spaces, incorporate climate considerations into urban planning, and promote sustainable practices. These measures will help balance urban growth and improve resilience to climate impacts.

Several authors have studied surface temperatures and urban heat islands in Yaoundé. Valérie and Epo (2013) identified neighborhoods like Akwa and Essos, where temperatures can reach 35°C due to urban density and limited green spaces. Njimanted and Mobit (2013) noted similar hot zones in Douala. Our study highlights Briqueterie, Mokolo, Madagascar, Ekoudou,

Tsinga, and Nkom-Kana as particularly hot. Njoh (1999) pointed out that Bastos, Ngouso, and other areas in Yaoundé 1 are significantly affected during peak months. In Yaoundé 7, neighborhoods like Eetak and Oyom Abang also experience high temperatures. Ojuku et al. (2022) discuss the impact of Mfoundi's infrastructure on surface temperatures.

5.1.2. Climatic and urban factors amplifying urban heat islands in the city of Yaoundé

5.1.2.1. The densification of road development. An analysis of road distribution (Figure 4) in Yaoundé

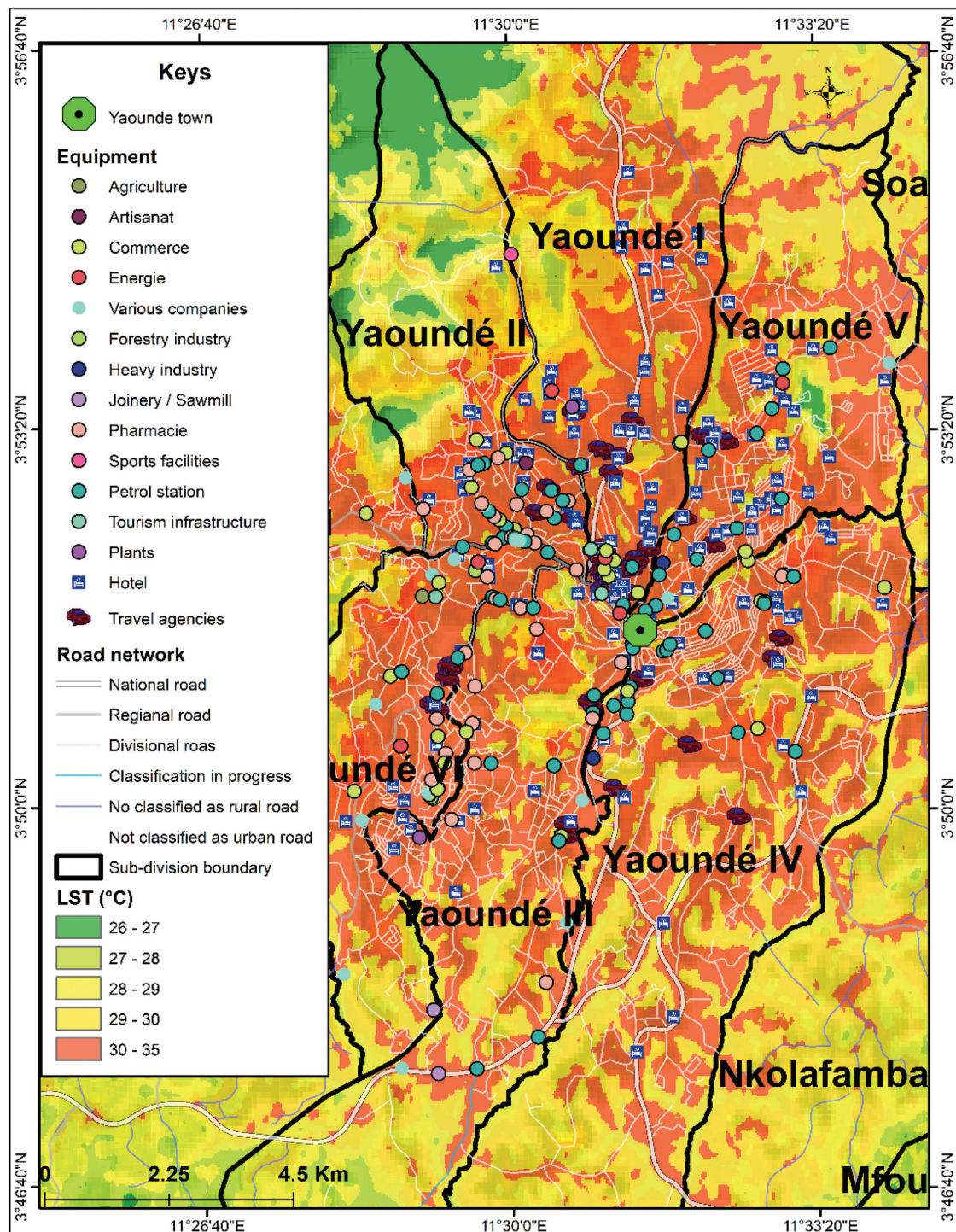


Figure 3. Visualization of surface temperatures at the scale of Yaoundé's district municipalities. Mapping associates urban heat island amplification factors, such as roads and socio-economic facilities. Data source: landsat 9 image from February 2025, Yaoundé urban community geospatial database.

shows significant unevenness, reflecting urban dynamics and growing mobility needs. About 60% of main roads are concentrated in central areas, facilitating access to essential services due to historical planning (Sietchiping and Nguendo-Yongsi 2008). This creates imbalances, as well-maintained main roads contrast sharply with neglected divisional and unclassified roads, which comprise around 40% of the network, particularly affecting the outskirts.

Congestion in central areas can increase journey times by up to 30% (Njimanted and Mobit 2013), impacting quality of life and economic productivity. Rapid urbanization further pressures the road network, underlining the urgent need for infrastructure improvements (CUY 2019).

A holistic approach that integrates environmental, social, and economic factors is vital for sustainable infrastructure development. Investments in public transport and green spaces are essential for addressing urban

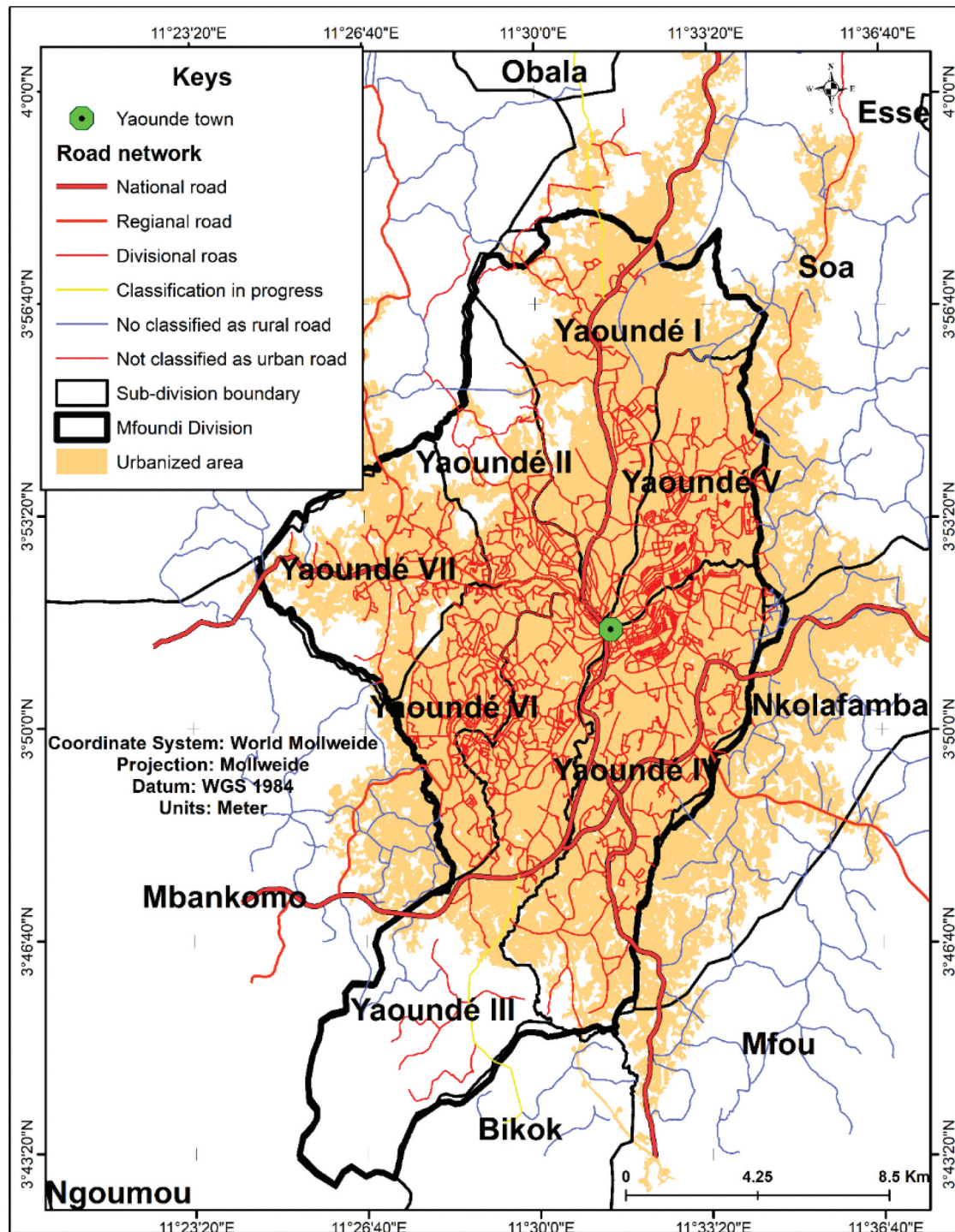


Figure 4. Yaoundé city road network. Data source: Ministry of Public Works (MINTP) database.

challenges and enhancing the quality of life while mitigating urban heat island effects (Sawaba et al. 2024).

5.1.2.2. *Densification of soil impermeability through buildings.* Between 2015 and 2025, Yaoundé experienced remarkable urban growth, with a significant increase in sealed areas. Satellite data indicates that this area expanded from 24,911.6 ha in 2015 to 38,857.24 ha in 2020, reaching 98,818.09 ha by 2025. Projections for 2030 estimate this area to be 132,815.44 ha (Figure 5).

This growth is driven by rising construction investments linked to increased housing demand from urbanization and population growth. Government initiatives and public-private partnerships have enabled the development of essential infrastructure, such as roads, schools, and hospitals, enhancing residents' quality of life. However, this rapid expansion presents challenges for urban planning and sustainability, necessitating a balance between development and environmental preservation.

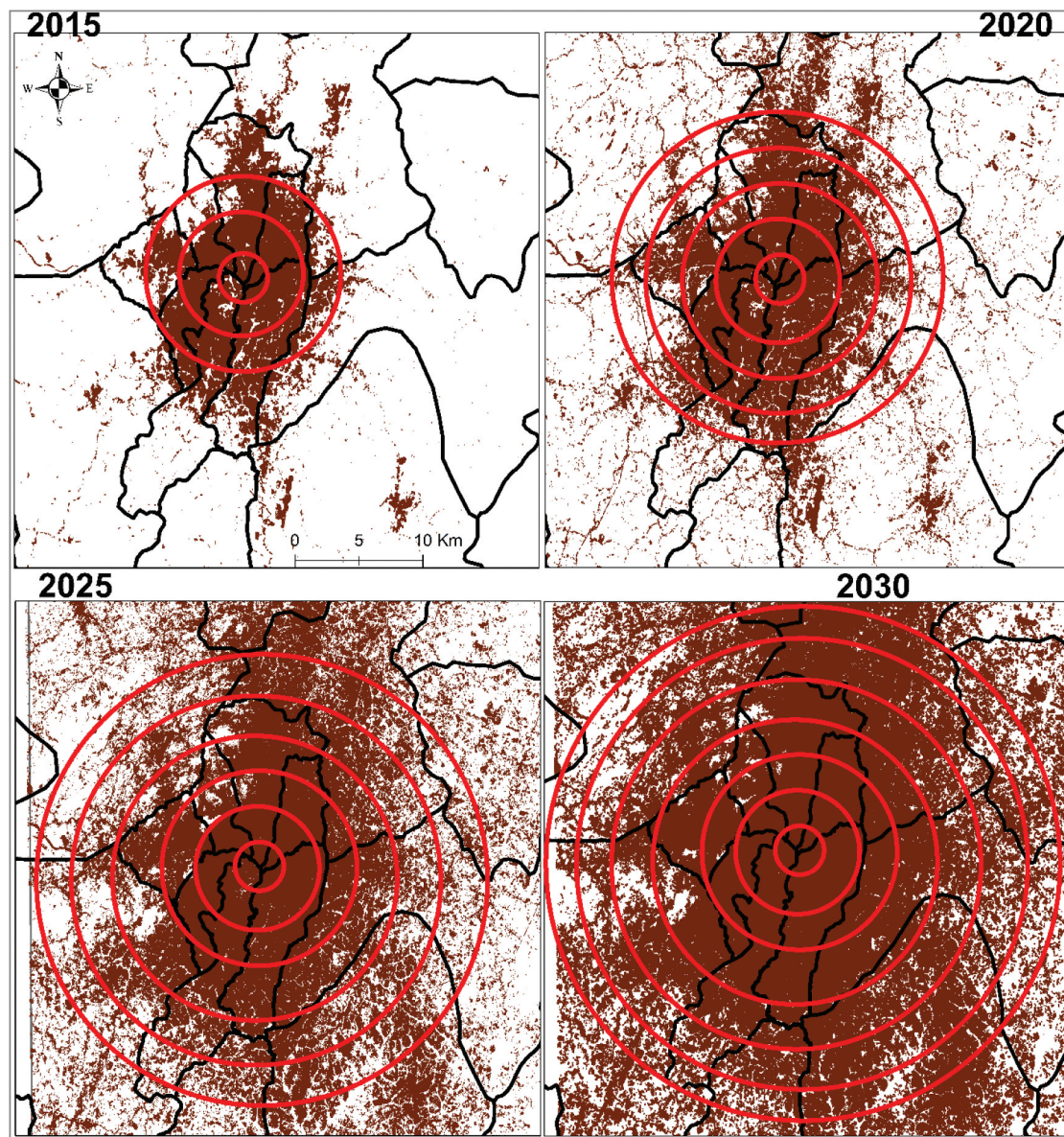


Figure 5. Expansion of built-up areas in the city of Yaoundé, between 2015 and 2025, with a projection to 2030. Data source: landsat images from 2015, 2020, 2025 and a projection to 2030.

With a radius of 2.5 km from the city center in 2015, the latter has spread to over 8.5 km in 2020, reaching 15 km in 2025, and could reach 18 km in 2030. Urban sprawl around Yaoundé is therefore spectacular. The natural environment is gradually being transformed into impermeable spaces (roads, buildings, etc.). This impermeabilization of the soil is a factor in the amplification of urban heat islands. This is more noticeable in the urban centre (Figure 6).

5.1.2.3. Deforestation around the city of Yaoundé between 2015–2025 and projected to 2030.

Deforestation around Yaoundé (Figure 7) from 2015 to 2025 has become a serious issue due to urban expansion and agricultural activities (Tchindjang et al. 2020). Rapid urbanization and population growth have increased the demand for land, resulting in significant forest loss. Logging for construction and illegal resource extraction

further harms ecosystems, threatening biodiversity and worsening problems like soil erosion and climate change.

The forest area has drastically reduced from 80,478 hectares to 48,025.3 hectares, a loss of 32,452.7 hectares in five years, averaging 6,490.5 hectares annually. This demonstrates the significant human impact on the environment and its potential effects on biodiversity, local climate, and quality of life. Deforestation also worsens the urban heat island effect and increases greenhouse gas emissions.

While various reforestation initiatives and awareness campaigns have been launched, their effectiveness is still being assessed. Understanding land use changes is essential for developing sustainable resource management and reforestation strategies, highlighting the urgent need for actions to protect natural resources and promote sustainable urban growth.



Figure 6. The urban center of Yaoundé has been completely transformed. The natural environment has been reduced to sparse clumps of trees. Picture credit: Eric Joël MAMA NKE.

This decline in vegetation is a factor who amplifying urban heat islands in the city of Yaoundé. The disappearance of vegetation cover and the multiplication of impermeable areas increase ground temperature (Tiwari et al. 2025). Figure 8 below shows the trends in land use classes over time and space.

Field observations and household surveys in Yaoundé reveal a significant decline in forest cover, primarily due to urban development, especially near the historic city center. Built-up areas in peripheral neighborhoods have further diminished vegetation. Notably, 71.5% of respondents reported constructing homes in primary or secondary forests, while 28.5% used cultivated land. Many (46%) estimated remaining vegetated areas at only 10%, with just 8% believing they account for 40% or more. This data underscores the urgent need for sustainable urban planning to preserve green spaces.

The perception of increasing heat in these neighborhoods is linked to reduced vegetation cover, with a positive Beta coefficient of 0.667 indicating that 8.52% of discomfort is due to declining tree cover. As vegetation diminishes, hot microclimates develop, exacerbated by building density and bare ground (Brunet and Viguier 2017). Heat perceptions are more common in densely built neighborhoods like Mvog-ada and Obili, while cooler temperatures are reported in peripheral areas. These disparities highlight the critical role of vegetation in shaping urban microclimates in Yaoundé.¹

5.1.3. Perceptions of hot weather trends in Yaoundé neighborhoods

The survey results from Yaoundé's neighborhoods reveal several key findings about residents' perceptions of heat. Notably, 91% of heads of household perceive a gradual increase in heat, indicating

widespread awareness of climate change, with 64.5% reporting a considerable increase. This underscores the urgency for action to mitigate heat effects.

Moreover, only 4.7% of respondents felt that heat had decreased, reflecting a predominantly pessimistic view of current weather conditions. The data show that heat is most acutely felt in the afternoon (46.4%) and at night (14.7%), highlighting critical periods for potential interventions, such as improving access to cooling solutions.

Additionally, 14.7% of respondents experience increased heat for most of the day, indicating vulnerability that could impact health and well-being. Overall, these findings underscore the need for tailored policies and community responses to address rising temperatures and protect urban populations.

5.2. Sensitivity to HCI in the city of Yaoundé

Sensitivity to heat is a critical vulnerability for communities (ADEME 2013). In Yaoundé, household income plays a significant role in thermal discomfort. A regression analysis reveals a negative Beta coefficient of -0.867 , indicating that discomfort decreases as income increases. The R^2 value shows that 15.2% of discomfort among household heads can be explained by income levels, as higher incomes facilitate access to better housing, outdoor rest areas, and superior cooling equipment.

5.2.1. Sensitivity factors of vulnerable populations to HCI in the city of Yaoundé

5.2.1.1. Socio-economic profile of monthly household income and poverty. Surveys on the income profile of urban residents in Yaoundé highlight key aspects of the city's economy. Notably, 80.8% of residents earn between 50,000 and 200,000 XAF

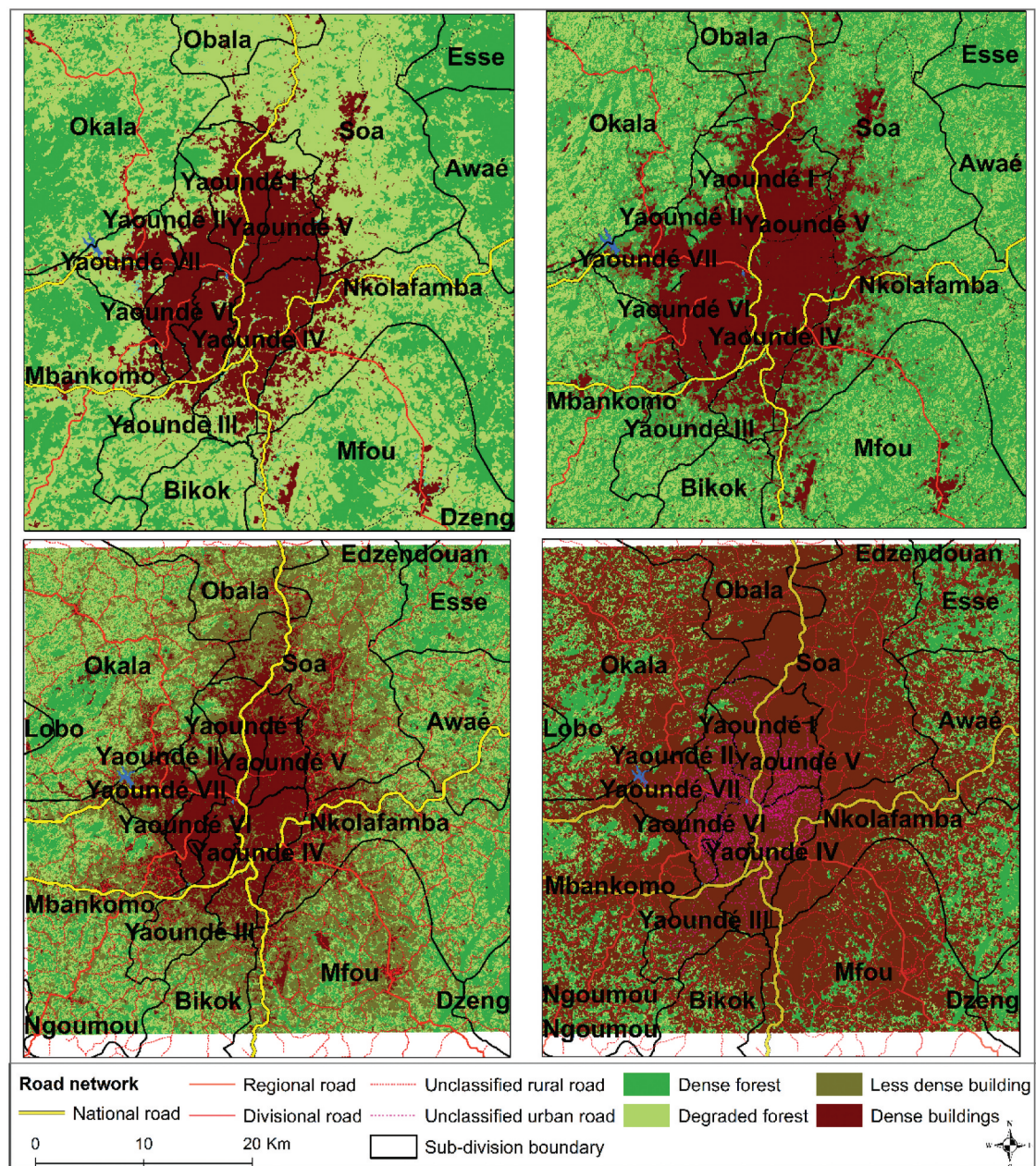


Figure 7. Spatio-temporal dynamics of land use, highlighting the drastic decline in forest cover around the city of Yaoundé. Data source: landsat images from 2015, 2020, 2025 and a projection to 2030.

(approximately 82.26 to 329.07 USD), indicating many live in precarious economic conditions associated with the middle class. Among these, 45.5% earn between 50,000 and 100,000 XAF, suggesting reliance on limited incomes from civil service jobs or the informal sector.

Additionally, 13.3% of households earn less than 50,000 XAF, classifying them as 'poor' and vulnerable to environmental factors like extreme heat, and lacking adequate cooling infrastructure. The few individuals earning over 200,000 XAF, mainly high-ranking officials, highlight income inequalities that limit access to essential resources (Figure 9). These findings emphasize the need for policies to improve living conditions and ensure equitable access to resources for vulnerable populations.

5.2.1.2. High mitigation costs and inequalities in access to certain basic social services in the city of Yaoundé. Variations in electricity consumption, particularly for air conditioning, are influenced by household equipment use, especially during the dry season when overheating increases energy needs. Households in structured neighborhoods spend between XAF 20,000 and over XAF 50,000 monthly for thermal comfort, while those in disadvantaged areas rely on intermittently used fans, resulting in lower bills but limited comfort. This situation highlights spatial inequalities, as affluent households access modern technologies, while disadvantaged populations face unequal adaptation capacities due to the inability to afford air-conditioned homes, which can better manage comfort and address energy justice issues. Addressing these disparities requires public

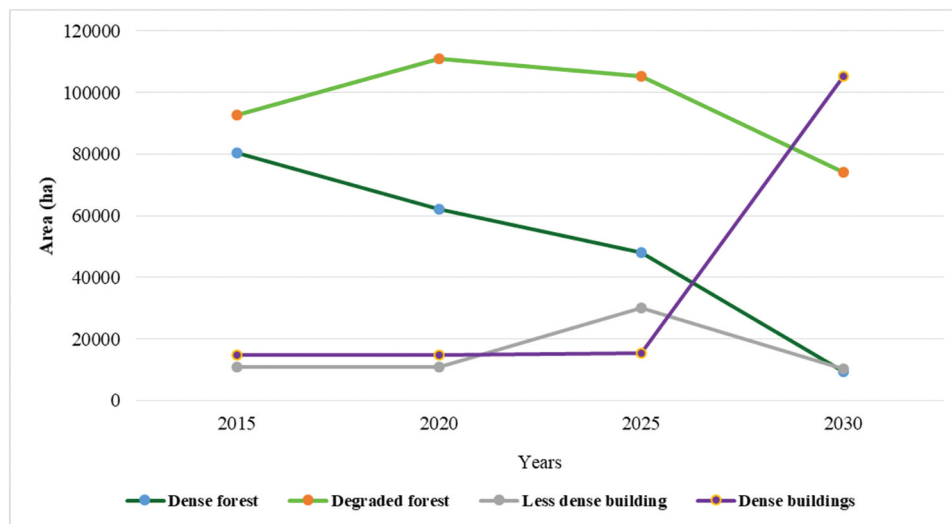


Figure 8. Spatio-temporal dynamics of different land-use classes around the city of Yaoundé, between 2015 and 2030. Data source: landsat image processing for the years 2015, 2020, 2025, and a projection to 2030.

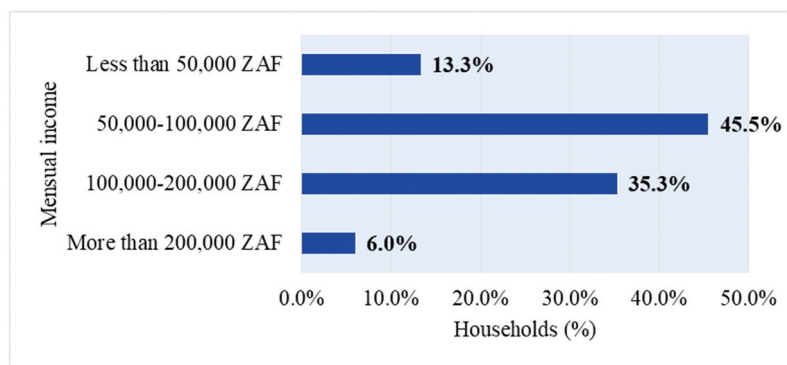


Figure 9. Approximate monthly income of heads of households surveyed. Source: field surveys, February (2025).

policies that ensure equitable access to energy technologies and promote sustainable solutions for inclusive development.

5.2.2. Impact on health (heat-related illnesses) and well-being (access to health services) in the city of Yaoundé

Moreover, thermal discomfort poses significant health risks, as excessive temperatures can have harmful effects on human health (Geddes 2023). This underlines the need to address the health issues associated with urban heat islands.

According to field investigation, urban residents' perceptions in Yaoundé reveals significant health impacts from heat. Notably, 55.2% of household heads report headaches and fatigue, while 33.3% experience insomnia, indicating the detrimental effects of elevated temperatures. Dizziness (8.3%) and respiratory difficulties further highlight health concerns linked to extreme heat.

These findings emphasize the urgent need for interventions, including improved cooling infrastructure and education on heat management. Public health programs are crucial for raising awareness

and promoting adaptation strategies to protect vulnerable populations, highlighting the necessity for a proactive response to worsening climatic conditions in Yaoundé.

5.3. Assessment of the capacity and strategies to adapt to HCI in the city of Yaoundé

5.3.1. Identifying existing resources

Identifying resources to adapt to urban heat islands (UHIs) in Yaoundé is vital for effective strategies. Existing infrastructure can be enhanced with sustainable features like shaded areas and green spaces. Government programs, such as the National Urban Development Plan, support environmental sustainability and fund UHI mitigation projects, including greening public spaces.

Collaboration with local and international organizations can provide resources for initiatives like green roofs and rainwater harvesting. A thorough inventory of available resources and cooperation among public, private, and community stakeholders is essential for strengthening Yaoundé's resilience to UHIs.

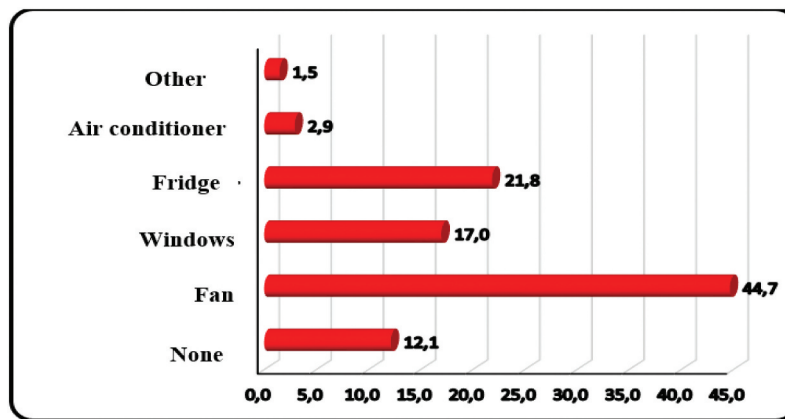


Figure 10. Adaptation options according to household. Source: field survey, February 2024.

5.3.2. Existing adaptation strategies (e.g. creation of green spaces, awareness-raising initiatives)

Surveys reveal various adaptation strategies among Yaoundé residents in response to elevated temperatures. Notably, 44.7% rely on artificial ventilation, while air conditioning usage accounts for only 2.9%, likely due to its high costs. Opening windows accounts for 17% of efforts to enhance air circulation, though this may be inadequate during peak heat. Informal strategies, like spending time on balconies, also emerge. While there is an emphasis on regular hydration and antiperspirant use, only 1.5% adapt their clothing style, indicating limited acceptance of fashion changes (Figure 10). Overall, these findings underscore that residents face challenges in adapting, highlighting the need for policy interventions to enhance access to cooling infrastructure and raise awareness about effective adaptation practices.

These strategies entail significant economic costs and environmental impacts. A survey reveals that 82% of households consider urban heat island-related expenses a financial burden, while only 3% report no impact. Ecologically unsustainable measures, like artificial ventilation, increase energy consumption and strain water resources, as 71.9% of the country's energy comes from hydroelectric sources (ENE0 2023). Additionally, antiperspirant sprays release harmful aerosols, worsening respiratory and cardiovascular issues.

In Yaoundé, responses to heat challenges include nature-based solutions and individual actions. Public authorities are afforesting pedestrian areas and creating urban forests and gardens (Figure 11), while residents adopt practices like opening shutters and limiting outdoor exposure to reduce discomfort (Rey et al. 2009).

The analysis of the price profile of these electrical appliances and the average monthly costs associated

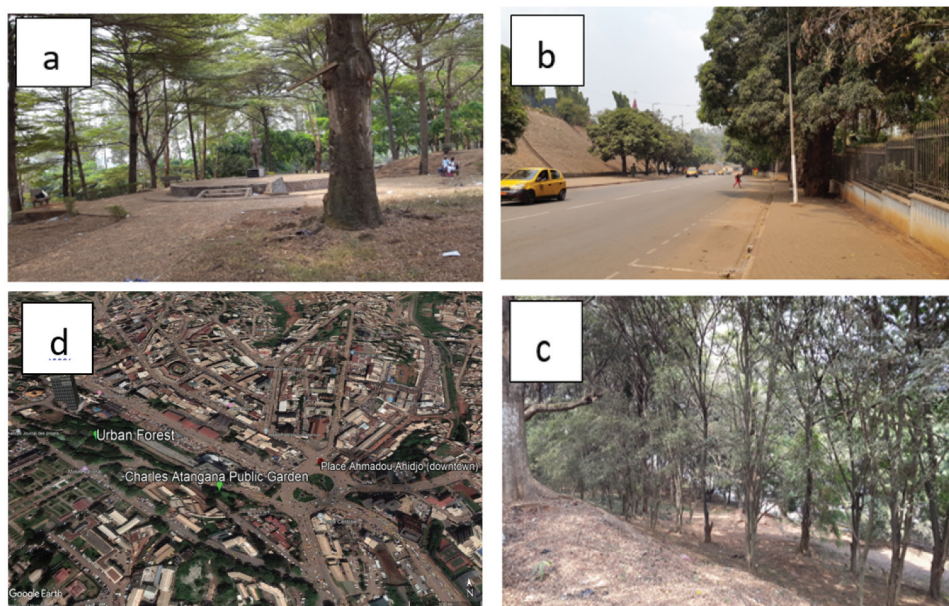


Figure 11. a) Charles Atangana public garden; b) street trees; c) urban forest in front of Boulevard de la Liberté; d) Aerial view of downtown from Google Earth Pro, 2025.

Table 6. Price profile of refrigeration and air conditioning Appliances used in households in Yaoundé during heat periods.

Refrigeration and Air Conditioning Appliances	Ranges/Models	Price in ZAR	Price in Euro (€)
Air Conditioner	9000–12000 BTU, 1.25–1.5 HP	190,000–225,000	289.65–343.01
	24,000 BTU/3 HP	320,000–385,000	487.84–586.93
Refrigerator	Entry-level	100,000–150,000	152.45–228.67
	Mid-range	180,000–250,000	274.41–381.12
	High-end	Up to 800,000	Up to 1,219.59
Freezer	100 L–150 L	110,000–150,000	167.69–228.67
Fan	Stand and wall-mounted	18,000–50,000 (varies by brand)	27.44–76.22
	Air cooler/dual-blade fan	Up to 140,000	Up to 213.43

Source: Field surveys, February 2025.

Table 7. Estimation of average additional monthly costs related to the use of refrigeration and air conditioning appliances in Yaoundé.

Refrigeration and Air Conditioning Appliances	Additional Electricity Consumption (in KWh/month)	Additional Monthly Expenses (in ZAR)	Additional Monthly Expenses (in Euro)
Fan	10 to over 30 depending on usage intensity	800–2,400	1.22–3.66
Refrigerator	25 to over 60	2,000–4,800	3.05–7.32
Freezer	15 to over 50	1,200–4,000	1.83–6.10
Air Conditioner	40 to over 400	3,200–32,000	4.88–48.78

Source: Field surveys, February 2025.

with their use (Tables 6 and 7) highlights these differences. Based on this data, it is very difficult for the majority of surveyed households (58.8%), who earn an income of 100,000 ZAR or less, to afford the minimum purchase prices of a refrigerator or air conditioner, which are approximately 100,000 ZAR (€152.45) and 190,000 ZAR (€289.65), respectively. Depending on the intensity of use, the estimated additional monthly expenses related to electricity consumption range from 2,000 to 4,800 ZAR (€4.88–€48.78) for refrigeration and from 3,200 to 32,000 ZAR (€4.88–€48.78) for air conditioning.

Most of Yaoundé's public gardens have been designed without considering climate change adaptation (Assako Assako 2012; UNDP 2024). While these green spaces help soften temperatures, effective heat-wave mitigation policies are lacking in residential and business areas. Literature suggests solutions like urban planning, blue spaces, cooling areas, and permeable surfaces, which offer economic and environmental benefits (Gago et al. 2013; Drapeau et al. 2021; Ahmed et al. 2024). However, their implementation is hindered by a gap between research and public policy (He et al. 2023). Approximately 82.5% of the population experiences the effects of heat in dry seasons (Brou et al. 2024; Li et al. 2025), influenced by the time of day.

5.3.3. The importance of community involvement and local knowledge in adaptation

Community engagement and local knowledge are crucial for adapting to urban heat islands (UHIs) in Yaoundé. Active participation allows residents to identify specific needs and develop tailored solutions. Surveys indicate that over 95% of city dwellers are willing to combat UHIs, enhancing collective

responsibility for sustainability. Leveraging local insights can promote tree planting and green space development, reducing ambient temperatures. A collaborative partnership between local authorities and communities, rooted in traditional knowledge, is essential for effective adaptation to UHIs.

5.4. Correlations observed between high temperatures and socio-economic indicators, highlighting implications for vulnerable populations

Using a simple regression method, the results indicate a statistically significant causal relationship, with

Table 8. Simple regression between reduction in vegetation cover and assessment of discomfort in the heat.

Model	Non-standardized coefficient		Standardized coefficient		
	B	Standard error	Beta	t	Sig
Constant	0,32	0,335		1,275	0,110
Heat discomfort	0,667		0,306	11,112	0,000
P	0,000				
F	105,6				
R ²	0,852				

Data source: field survey, February 2024

Table 9. Simple regression between income and level of discomfort in the dry season.

Modèle	Non-standardized coefficient		Standardized coefficient		
	B	Standard error	Beta	t	Sig
Constant	0,42	0,335		1,376	0,106
Heat discomfort	−0,867		0,408	12,112	0,000
P	0,000				
F	113,14				
R ²	0,1552				

Data source: field survey, February 2024

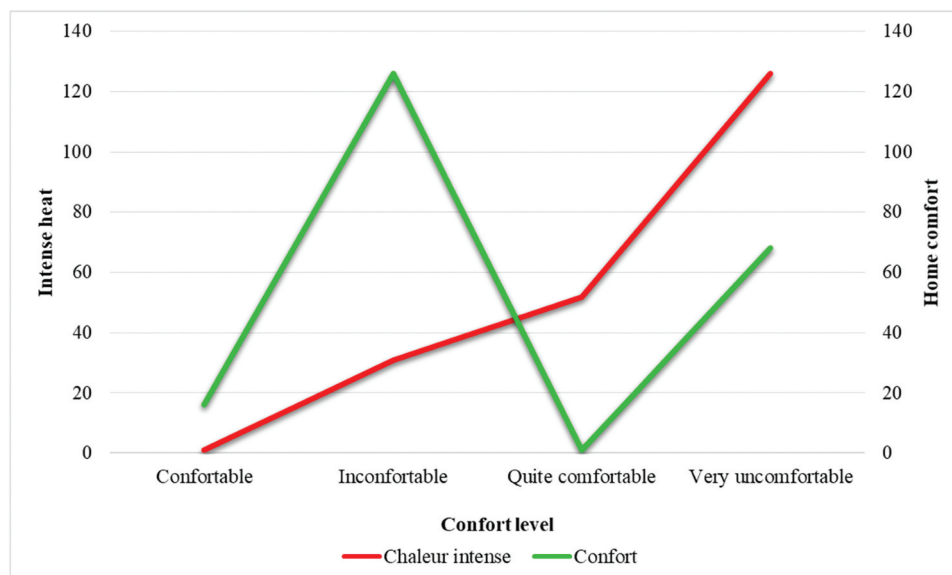


Figure 12. Variation in comfort levels with urban heat islands. Data source: field survey, February 2024.

$F(1:211) = 113.14$ and $p = 0.000$ (< 0.005). This confirms a correlation between the decrease in vegetation cover and the intensification of the urban heat island (UHI) in Yaoundé. Additionally, residents' income levels amplify their vulnerability to UHI, as shown in Table 3, where the model is also statistically significant ($F(1:211) = 105.6$ and $p = 0.000$).

These factors are crucial for understanding the vulnerability of Yaoundé's populations (Tables 8 and 9). An R^2 of 0.852 indicates that 85.2% of the variations in UHI can be explained by the loss of vegetation. This highlights the importance of managing vegetation cover to mitigate elevated urban temperatures.

This correlation relies on several assumptions: (i) Causal Relationship: The hypothesis posits that reduced vegetation cover intensifies the urban heat island (UHI) effect in Yaoundé, directly impacting urban temperatures. (ii) Economic Vulnerability: The income level of residents is believed to influence their vulnerability to the UHI, with lower-income households more affected due to limited access to protective resources like air conditioning. (iii) Statistical Significance: The regression models used are assumed to be appropriate for establishing significant correlations between the variables, justifying the statistical tests employed (F and p-values).

However, the model has limitations: (i) Data Limitations: The quality and availability of data on vegetation cover and urban temperatures may distort results, especially if spatial resolution is only 15 m. (ii) Complexity of Interactions: The relationship between vegetation cover, UHI, and income may be influenced by other factors, such as urbanization, limiting the model's scope. (iii) Temporality: The study does not account for seasonal variations in vegetation cover and UHI, which could affect the robustness of its conclusions, especially concerning long-term effects.

While the results indicate a correlation, they do not necessarily prove causation. Further studies would be needed to establish stronger causal links between the variables.

5.5. Correlations observed between high temperatures and comfort in home

The analysis of questionnaire data reveals significant discomfort among respondents who face intense heat (Figure 12). Of the participants, 126 often feel 'Uncomfortable,' while only 16 report feeling 'Comfortable.' Many express being 'Very often' uncomfortable, indicating widespread discomfort. In contrast, 31 respondents feel 'Sometimes' comfortable, revealing variability in comfort perceptions.

Although 52 participants consider themselves 'Quite comfortable,' most still experience discomfort in hot conditions. These findings underscore the need for interventions – such as optimizing air conditioning, wearing appropriate clothing, and taking regular breaks in cool spaces – to improve well-being for those frequently exposed to heat.

6. Discussion

6.1. Surface temperature and seasonal variations in Africa

Seasonal variations in urban heat islands (UHIs) in Africa raise interesting questions, as they are influenced by a multitude of climatic, demographic and socio-economic factors. Take Accra, for example, where high temperatures during the dry season from November to March are exacerbated by rapid urbanisation and a lack of vegetation cover (Zhang and

Menendez 2020; Garuma 2023). This highlights how urban dynamics can intensify the effects of heat.

In Nairobi, although rain provides temporary relief, the small amount of green space limits the long-term beneficial effects (Mwanzu et al. 2023). Similarly, in Abidjan, Ymba (2022) established a link between high building density and health problems such as migraines and fatigue, highlighting particularly vulnerable neighbourhoods. This finding also resonates in Johannesburg, where Usman et al. (2023) found that building density contributes to maintaining high temperatures, thereby exacerbating socio-economic inequalities.

In the North African context, studies such as those by Soufiane et al. (2025) on urban expansion in Oran, or El Ghazouani et al. (2021) on the impacts of IHUs in Morocco, highlight the importance of appropriate urban management. Ncongwane et al. (2021) also reviewed the health impacts of heat stress across the continent, stressing the need for targeted public health policies.

Encouragingly, some cities, such as Lagos, are beginning to implement adaptation strategies (Srivastava et al. 2021). Meanwhile, Addis Ababa and Dakar are focusing on greening initiatives, such as tree planting and the installation of green roofs (Mahmood and Hassan 2025). These efforts reflect a growing awareness of the challenges posed by urban heat islands and the importance of concerted action to mitigate their effects on urban communities.

6.2. Vulnerability to urban heat islands (UHIs) in Africa and climate justice

Rising temperatures, along with diverse socio-economic and spatial conditions, heighten the vulnerability of poor populations, particularly in informal settlements. This aligns with findings from other Sub-Saharan African cities, where urban informality and economic disparities worsen the situation (Dodman and Mitlin 2014; Cobbinah et al. 2015).

The study of UHI vulnerability in Yaoundé emphasizes the need to reassess urban policies within the climate justice framework. Similar studies in Accra (Erdiaw-Kwasie et al. 2020), Nairobi (Tan et al. 2021), and Lagos (Elias and Omojola 2015) show that inequalities in access to housing, air conditioning, and green spaces perpetuate socio-spatial segregation.

In Yaoundé, UHI vulnerability exacerbated by inequalities calls for a critical reevaluation of urban policies through an equity lens (MINEPDED 2015). Effective adaptation must integrate social, economic, and spatial inequalities, ensuring equitable access to infrastructure and community involvement (Adegun and Ayoola 2021).

Mitigation strategies such as urban planning, blue spaces, and permeable surfaces offer economic and

Table 10. Summary of public policy documents relating to the public health sector in Cameroon.

Document Title	Year	Key Focus Areas	Author
National Health Policy	2016	Overall health system strengthening	MINSANTE
Health Sector Strategic Plan	2018	Disease control and prevention	MINSANTE
Public Health Act	2011	Regulation of health services	MINSANTE
National Program for Health	2019	Health promotion and education	MINSANTE
Emergency Health Response Plan	2020	Preparedness for health crises	MINSANTE

environmental benefits (Gago et al. 2013; Drapeau et al. 2021; Ahmed et al. 2024). However, Cameroon's urban planning often prioritizes modern infrastructure, overlooking the need for inclusive measures and effective health policies, many of which remain unoperational.

6.3. Urban policies and planning in Cameroon

In Cameroon, numerous public policy documents pertain to public health (Table 10). However, these policies often remain latent and lack effective operationalization. Consequently, a significant portion of the population resorts to 'managing as best they can' when addressing their health issues.

This summary highlights the existing frameworks aimed at improving public health, yet underscores the gap between policy formulation and practical implementation.

6.4. Population growth, increased demand for transport, and urban pollution

Rapid urban population growth in African cities has increased mobility demand, leading to more transportation modes and rising pollution, which impacts the microclimate. Atangana Bamela (2025) examines urban mobility challenges in Cameroon, projecting a population of 3 million by 2025. With a motorization rate of 10 vehicles per 100 inhabitants, traffic congestion causes economic losses and worsens air quality, affecting public health. These challenges highlight the need for a sustainable urban mobility plan.

In Dakar, informal taxi drivers are essential for affordable urban transport, generating employment and income. Improvements like training programs and better infrastructure could enhance their working conditions and safety, addressing the needs of the growing population.

6.5. Spatial inequalities and urban informality in Africa

In West Africa, spatial inequalities are evident in the uneven distribution of resources and urban

infrastructure, as seen in Côte d'Ivoire (Pagès 2008). Major cities like Lagos and Abidjan attract large migrations, resulting in slums with limited basic services, particularly affecting marginalized populations like women and youth (Mbianda Kemadjou 2020).

In Central Africa, urban informality is widespread, resulting in disparities in access to quality public spaces and services, as observed in the Republic of the Congo (Pinto et al. 2023). Governments face challenges in formalizing the informal economy while respecting workers' rights (Thorsen 2012), with local initiatives aiming to integrate informal actors into sustainable urban plans.

In South Africa, spatial inequalities rooted in apartheid create divides that limit economic opportunities (Scheba et al. 2021). Informal settlements on urban peripheries reflect ongoing socio-economic exclusion (Dissanayake et al. 2025). Effective public policies must address these imbalances and promote the participation of marginalized populations in urban planning.

6.6. Recent climate justice policies in southern countries

Okereke and Coventry (2016) analyze climate justice in the context of the Paris Conference, highlighting power dynamics and inequalities in climate negotiations. They stress the need for social justice principles to ensure fair representation for vulnerable countries.

Owona (2019) explores the intersection of human rights and climate justice in Africa, noting that climate change threatens fundamental rights, disproportionately impacting marginalized communities (Ogunbode 2022). He advocates for integrating human rights into climate policies and calls for collective mobilization to defend affected populations' rights.

In West Africa, countries face climate change challenges like rainfall variability and rising sea levels, prompting policies to enhance resilience (Williams et al. 2023). The West Africa Sustainable Development Program promotes local initiatives and climate justice objectives (Domegni and Azouma 2022).

Central Africa focuses on protecting tropical forests critical for climate regulation (Tachega et al. 2025). Sustainable development strategies in countries like Cameroon and the Democratic Republic of the Congo respect indigenous rights and promote social equity (Bond 2014; Enjema et al. 2020).

South Africa faces unique climate justice challenges due to its reliance on fossil fuels (Allen 2015). The country's climate policies aim to reduce carbon emissions while supporting vulnerable communities through just transition programs that provide new skills in renewable energy (Nkrumah 2021; Barnwell and Wood 2022).

6.7. Perspectives and initiatives for mitigating UHI in African cities

The prospects for mitigating urban heat islands (UHIs) in African cities, including Yaoundé, require an integrated approach. Firstly, the creation and preservation of green spaces, such as parks and community gardens, are crucial to lowering local temperatures and improving quality of life (Usman et al. 2023).

Secondly, using reflective building materials and regulating impervious surfaces can reduce heat build-up (Mwanzu et al. 2023).

Thirdly, tree planting and the creation of green corridors play an essential role in mitigating the effects of UHI.

In Cameroon, the 'Sahel Vert' operation (Dongmo 2008; Djongyang 2022) launched in 1973 effectively combated desertification in northern regions by mobilizing local communities to plant millions of trees, enhancing reforestation and sustainable agriculture (Awono et al. 2023). This initiative raised environmental awareness and improved living conditions, followed by the ambitious 'Great Green Wall' project, viewed as utopian by some (Mugelé 2018).

In Yaoundé, Reunification Park, inaugurated in 2000, provides green spaces and boosts biodiversity, including Saint Anastasia wood. Reforestation campaigns in neighborhoods like Messa and Bastos have planted thousands of trees to reduce pollution and erosion, improving air quality and showcasing the city's commitment to sustainable urban development (Nkwemoh and Tchindjang 2018) (Figure 13).

Fousséni et al. (2019) analyze the flora of urban green spaces in Atakpamé, Togo, highlighting their biodiversity and importance for residents' well-being and micro-climatic improvement. Their findings reveal significant floristic diversity, though many species are threatened by urbanization. The authors stress the need to preserve and enhance these green spaces to support urban ecosystems and improve environmental quality. They recommend awareness initiatives and sustainable management practices to conserve local flora.

An interdisciplinary approach combining climatology, urban planning, and social sciences is essential for developing effective strategies. Integrating these measures into urban planning will help Yaoundé and other African cities better address urban heat island (UHI) challenges and promote healthier, sustainable environments.

7. Recommendations

To effectively combat urban heat islands (UHIs) in African cities, we recommend several key actions for urban management authorities. First, land use planning should prioritize incorporating green spaces,

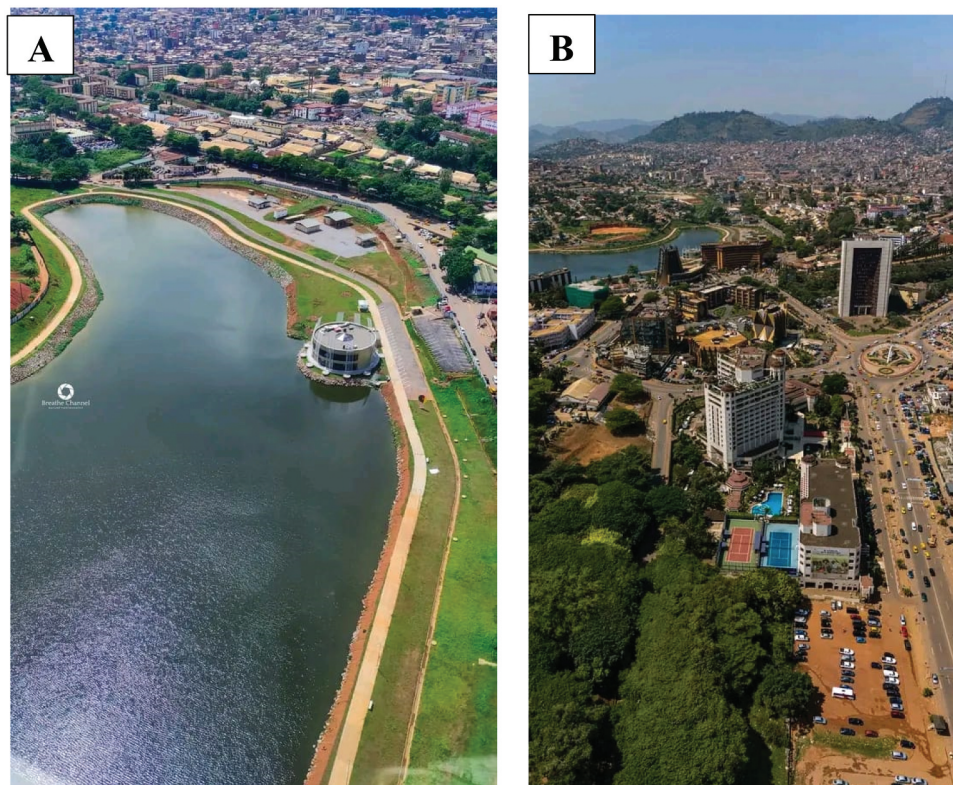


Figure 13. Aerial view of Yaoundé city centre: (A) municipal lake with a line of trees to the north; (B) administrative centre with greenery on the periphery. Picture credit: Eric Joël MAMA NKE.

such as parks and tree-lined areas, into new developments, alongside adaptive zoning regulations that promote low-thermal-impact construction methods like green roofs and reflective materials. Second, investing in basic infrastructure is crucial for modernizing informal settlements, improving access to potable water and electricity, and providing training programs on sustainable construction and passive cooling tailored to local needs. Additionally, enhancing health services through public awareness campaigns about heat effects, improving healthcare access for heat-related illnesses, and establishing monitoring systems for public health impacts during heatwaves are essential. Intersectoral collaboration among government agencies, NGOs, and local communities can foster integrated strategies and innovative funding mechanisms to support sustainable development projects. Finally, supporting impact studies and promoting innovation in cooling technologies and water management will help communities adapt to rising temperatures. By integrating these recommendations into urban governance, cities can better prepare for the challenges posed by UHIs and improve residents' quality of life.

8. Conclusion

The analysis of urban heat islands (UHIs) in Yaoundé highlights significant challenges from rapid urbanization and climate change. Surface temperatures rose

from 24–31°C in 2015 to 25–33°C in 2020, and are projected to reach 38°C by 2030. The increase in hard surfaces has surged from 24,911.6 hectares in 2015 to an expected 132,815.44 hectares by 2030.

Yaoundé's population has grown dramatically, from 59,000 in 1957 to nearly 4.1 million in 2020, resulting in a high density of 13,486 inhabitants per square kilometer, primarily due to rural-to-urban migration. This growth has created neighborhoods with varying characteristics, where urban temperatures can be up to 5°C higher than those in rural areas, exacerbating heat stress, particularly for vulnerable communities. Vegetation cover has sharply declined, with dense forest areas decreasing from 80,478 hectares in 2015 to 48,025.3 hectares in 2025. Industrial emissions also contribute to the heat problem, with nearly 40% of residents living in areas that exceed comfortable temperature levels. To address these escalating challenges, decision-makers must implement effective strategies that include adaptation measures, public awareness campaigns, and nature-based solutions, such as increasing green space by 30% in Yaoundé by 2030.

Note

1. Above all, forests cool the air through their shading effects (intercepting radiation which, in fact, does not contribute to heating built-up surfaces) and through their action on soil water evaporation (via leaf

transpiration). This can lead to a significant drop in surface temperature. This tends to reduce the heat island phenomenon (Brunet and Viguier 2017).

Authors' contributions

Philippe Mbevo Fendoung contributed to the conceptualization, methodology, mapping, analysis, and writing of the article following his fieldwork. Abassombe Guy Donald's role consisted of constructing the method and writing. Kamgho Casimir contributed an analysis. Tchindjang Mesmin's role involved reviewing. Aurélia Hubert-Ferrari helped restructure and improve the English language. All the authors read and approved the version.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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