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Understanding Urban Growth through Heat Islands Using Remotely Sensed Data: Yaounde Case Study, Cameroon

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Abstract

Studies in urban dynamics have focused on population growth, urban sprawl and activities expansion to determine, understand and study the phenomenon of urbanization in the world. The methods used in these studies have explore remotely sense data from Global Positioning Systems (GPS), satellite imagery, aerial and ground photography for interpretation, analysis and explanation of urban land use and land cover evolution. This data is often combined with ground observations and other methods in social sciences to understand urban growth. In this article, data is tapped from temperature differences analysis in multi-date satellite images and combined with population statistics, human activities and infrastructure build up to explain the phenomenon of urbanization. The results of the findings will enrich our knowledge in Urban Geography on approaches and methods used in understanding urbanization and its problems. Drawing on case study material from Yaounde in Cameroon, this article examines how remote sensing techniques can help in understanding urban heat island in Yaounde and its negative outcomes on urban population, activity and the environment. As the study shows, urban growth has a direct relation with temperature increase and an inverse relation with vegetation change. Also, Increase in bare surfaces due to deforestation for development and settlement increases surface temperature and vice versa. Vegetation regulates surface temperature by absorbing energy from solar radiation and remission in the form of latent heat through the process of photosynthesis. Analysis of surface temperature increase through remote sensing techniques, urban land use evolution, determinants and implications of Yaounde heat islands constitute the focus of this paper. The implications of rise in surface temperature and relations with urban growth are important for decision making. This knowledge is essential for urban geography research, new methodological approaches to urbanization and policy.

Keywords

Urban Heat Islands, Urban Growth, Remote Sensing, Temperature, Yaounde

1. Introduction

Sub Saharan African countries today are experiencing rapid rate of urbanization, Yaounde, the capital of Cameroon, is not an exception. The built-up space, activities and population of African towns (lagos in Nigeria, Abidjan in Ivory Coast, Cotonou in Benin, Nairobi in Kenya, Arusha in Tanzania and Yaounde in Cameroon amongst others) have increased (Ojuku and Mengue, 2017). Global temperatures in these cities are also increasing faced with population growth, human activities and climate change. Despite these rising temperatures, little is known about the link between urban growth, heat islands and application of remote sensing for its understanding. Studies carried out in urban geography to understand the expansion of our cities have focus on descriptive approaches, quantification and analysis of urban activities, mapping of land cover and land use change using aerial photographs and high-resolution satellite images. How urbanization can be understood through temperature differences involving the calculation of iron oxide indice in heat islands using satellite imagery is little known. Using multidate satellite images (ETM, TIRS, LC8, and TIRS), image processing softwares accompanied by ground truth verification, surface temperatures variations of the land can be determined to map out the urban build up space and other land uses. This information can help to enrich our knowledge of urbanization. The difference in temperature compared with field data (population statistics, urban activities and land cover/land use) can help to bring out the determinants of temperature variation for easy understanding of urban expansion. In Yaounde, unplanned urbanization characterized by haphazard construction resulting from poor implementation of urban plans and laws, corrupt practices by land governors, illegal occupation of risk prone areas (forbidden for construction), influences of multi-actors involved in urban space planning and management are some of the drivers identified in urban space mismanagement and disorder (Ojuku and Mengue, 2017; Ntemngweh, 2022; Choaumo, 2012). The outcome of haphazard build up, land occupation and rise in urban temperature in Yaounde are many. Urban land occupation and exploitation has increased and expanded leading to destruction of forests, water resources, soil degradation, pollution and biodiversity reduction in urban wetlands and peripheries. The expansion of build up space has also resulted to social, economic and cultural tension, conflicts and problems. These newly occupied areas in the Yaounde urban space are witnessing aberrant weather pattern marked by exponential high surface temperatures and unpredictable rainfall that affect affects the town and population.

2. Approaches, Material and Methods

2.1. Approaches in Urban Studies

Application of remote sensing to determine heat islands for comprehension of urban growth is absent in many urbanization literatures. How city population, activities and heat Islands are related in urbanization is also not known. Heat islands and urban growth have however been investigated in isolation in urban studies. This is the case in Mauricie (Conde, 2010), Windsor (De Carolis, 2012). Conventional methods of studying urban heat island have been through observation, collection and association of meteorological data for description of urban growth. Other authors have studied urban heat islands by use of statistical methods to determine energy budget through the testing of hypothesis preset; application of computer modeling techniques marked by energy flux to observe urban effects and surfaces; and adoption of urban modelling and measurement using the physical scaled models and fluxes measurement in different cities (Sobrino, Jimenez, and Paolini, 2004; Bechtel et al., 2012). Yet some authors have established the relationship between urban forms and their climate effects through field projects carried out by researchers and improved urban models through measurement programmes (Bechtel et al., 2012). In some studies, urban Heat Islands have been studied using several indices (Normalised Difference Vegetation Index, Normalised Difference Bareness Index, and Normalised Build up Index) to find the correlation with temperature (Chen et al., 2006). Others have used Local Climate Zones characterization schemes involving the scoring of a sky view factor, terrain roughness, building surface and impervious fractions, surface energy admittance, surface albedo and anthropogenic heat flux based on photography and Google Earth imagery observation to understand heat islands (Yvonne, 2015). This paper proposes the use of satellite images derived from sensors or aerial apparatus that detect radiation emitted from distance surfaces to determine urban heat islands. The resulting image is processed using Erdas Imagine and ArcGIS softwares to determine temperature variations. This can be direct or indirect depending on the scale of measurement of surface temperature and sensor position. Even though many advances have been done in the methodology of study of urbanization and urban geography research, little is known in the temperature measure approach.

2.2. Material and Methods

In the methodology used for this paper, Landsat images of different dates have been exploited to calculate surface temperature for identification of heat islands in Yaounde. This temperature was correlated with urban activities and population data to comprehend the urbanization of the town. The images used were Landsat ETM (band 6) for 1999, 2000 and 2001, Landsat OLI and TIRS (Band 10 and 11) for 2001, 2015 and 2018 obtained from the National institute of Cartography-Cameroon. The processing involved conversion of pixels into radiance

for both images using single channel algorithm developed by Sobrino, Jimenez and Paolini (2004)

$$L_{\lambda} = \frac{\text{LMAX}_{\lambda} - \text{LMIN}_{\lambda}}{\text{QCALMAX} - \text{QCALMIN}} * (\text{QCAL} - \text{QCALMIN}) + \text{LMIN}_{\lambda}$$

For ETM and

$$L_{\lambda} = \text{ML} * \text{QCAL} + \text{AL}$$

for OLI/TIRS image.

This was then followed by conversion of the spectral radiance sensor into real temperature

$$\text{TEC}(^{\circ}\text{C}) = \frac{K^2}{\ln\left(\frac{Ki}{L_{\lambda}} + 1\right)} - 272.15 .$$

Finally, the actual temperature of the sensor (TEC) was converted into real surface temperature (RST) using the following equation:

$$\text{RST}(Z) = \text{TEC}/1 + W * \left(\frac{\text{TEC}}{p}\right) * \text{Ine}$$

with the assumption of unitary emissivity and also using the constance of pre-launch (Zanter et al., 2016). With the heat islands determined for urban area, vegetation indice (NDVI) was then associated and direct field control missions carried out to determine the causes of the heat islands. These findings were imperative to understand urban growth and expansion from new perspectives. Generating knowledge on the evolution of urban heat Islands through multi-date satellite image processing help in explaining the phenomenon of urban expansion (Sundara et al., 2012).

Population data for Yaounde was collected from the National Census on Population and Housing (BUCREP) and exploited to find out the link between urban growth and temperature variation. The data was integrated on land used maps covering old and new quarters within the period of study. Data on urban activities and green spaces was also collected from ministerial departments, Yaounde City Council and NGOs operating on the environment. This data was process and analysis to corroborate the relationship between urban growth, activities and urban heat islands. The results of these data were displayed on the maps integrated in the paper.

3. Study Site

Yaounde, also known as "city of seven hills" is the political capital of Cameroon. It is the second most populated town of Cameroon after Douala, with a total of 2,765,568 inhabitants in 2015 (BUCREP, 2010). Yaounde is the regional Head quarter of Mfoundi Division and the Centre Region. The town is located between longitude 11˚31'12 East and latitude 3˚52'12 North (**Figure 1**). The area has a diverse relief comprising high plateau varying between 700 and 800 metres

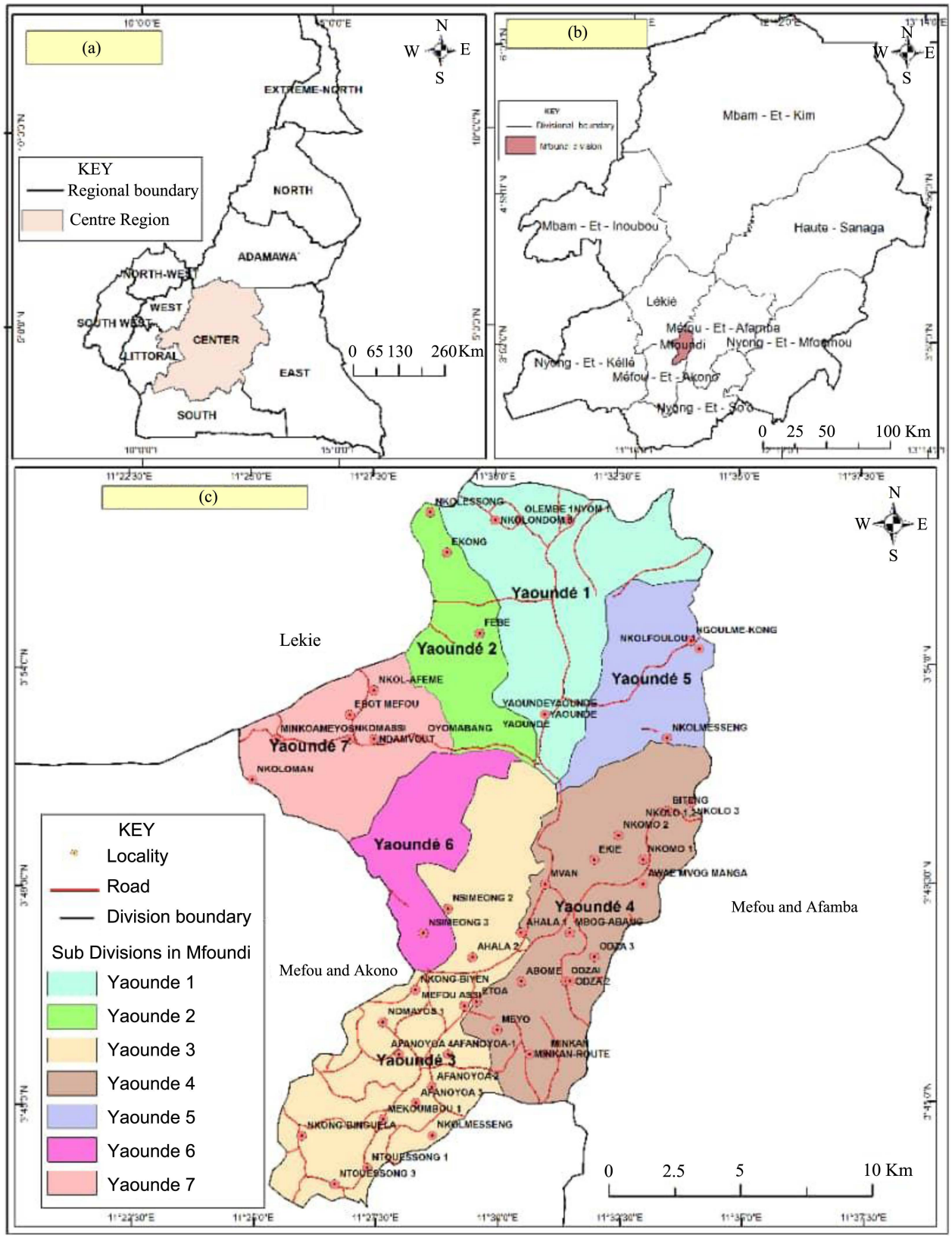

Figure 1. Location of Yaounde threatens the urban population, activity and the environment. Source: Ntemngweh, 2022. (a) Centre region in Cameroon; (b) Mfoundi division in centre region; (c) Mfoundi division.

of altitude crowned by round shape mountainous massifs that converge between 1000 and 1200 metres of altitude (Ojuku and Mengue, 2017). It is surrounded by Mefou-Akono in the West, Mefou-Afamba in the East, Mefou-Akono in the South and Lekié Division in the North. The town has a subequatorial climate with altitudes that moderate the temperature range. With deficits of rainfall, the climate has evolved with high temperatures resulting from the wanton destruction of its vegetation cover. This climate is characterized by alternation of two seasons (November-March for the long dry season, and June-August for the short dry season) and two rainy seasons (August-November for the long rainy season and April-June for the short rainy season). Average temperatures of 23.5˚C and rainfall of 1650 mm are recorded per year. The vegetation is of the intertropical type having a predominance of humid southern forest. Yaounde had a surface area of 14.800 hectares in 2002. Today the urban space has expanded to over 36,000 hectares (Tchindjang et al., 2020). The spatial distribution of heat Islands has changed with lands under development and population pressure warmer than other land use types.

4. Results and Discussion

4.1. Results

4.1.1. Vegetation Cover and Build up Space

Analysis of satellite images covering the Mfoundi area shows that Yaounde was much covered by forest and green spaces prior to the 1990s. Much of Mfoundi and its seven subdivisions was less populated and urbanized. The buildup space was less during this period and gradually increased over time in a well-defined process to invade forest lands (**Figure 2**).

As seen on this **Figures 2(a)-(c)**, the occupation of forest usually began by land transfer (>80% cases by purchase) from indigenes and deforestation for agriculture introduction. This was followed by construction of houses, population installation and establishment of commercial ventures such as schools, health services, poultry farms, building material stores which attracted other

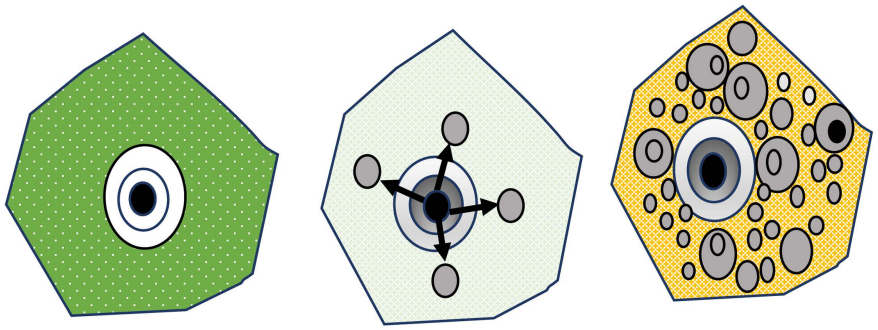

Figure 2. Stages of urban extension upon front development. Source: Conceived by Ojuku T. (2021), after Enault (2003) cited in Choaumo (2012). (a) Forest invasion; (b) Front development; (c) Urban sprawl.

populations to settle in the area. In this process vegetation was destroyed and replaced by build up space that conserved latent heat and increase surface temperature leading to development of heat islands. The Central Business District area of Yaounde at this time was restricted to the areas of Mokolo, Tsinga, Bastos, Mvog Ada, Etoa Meki, Essos, the Administrative area, Melen, Ngoaekelle (Figure 3 and Figure 4).

The neighbourhoods of this area were covered by much forest and farmlands. One observes a relationship between the vegetation loss in Yaounde since 1999, a continuous buildup and expansion of the town and variation in surface temperature. This loss of vegetation has been attributed to diverse socio-economic

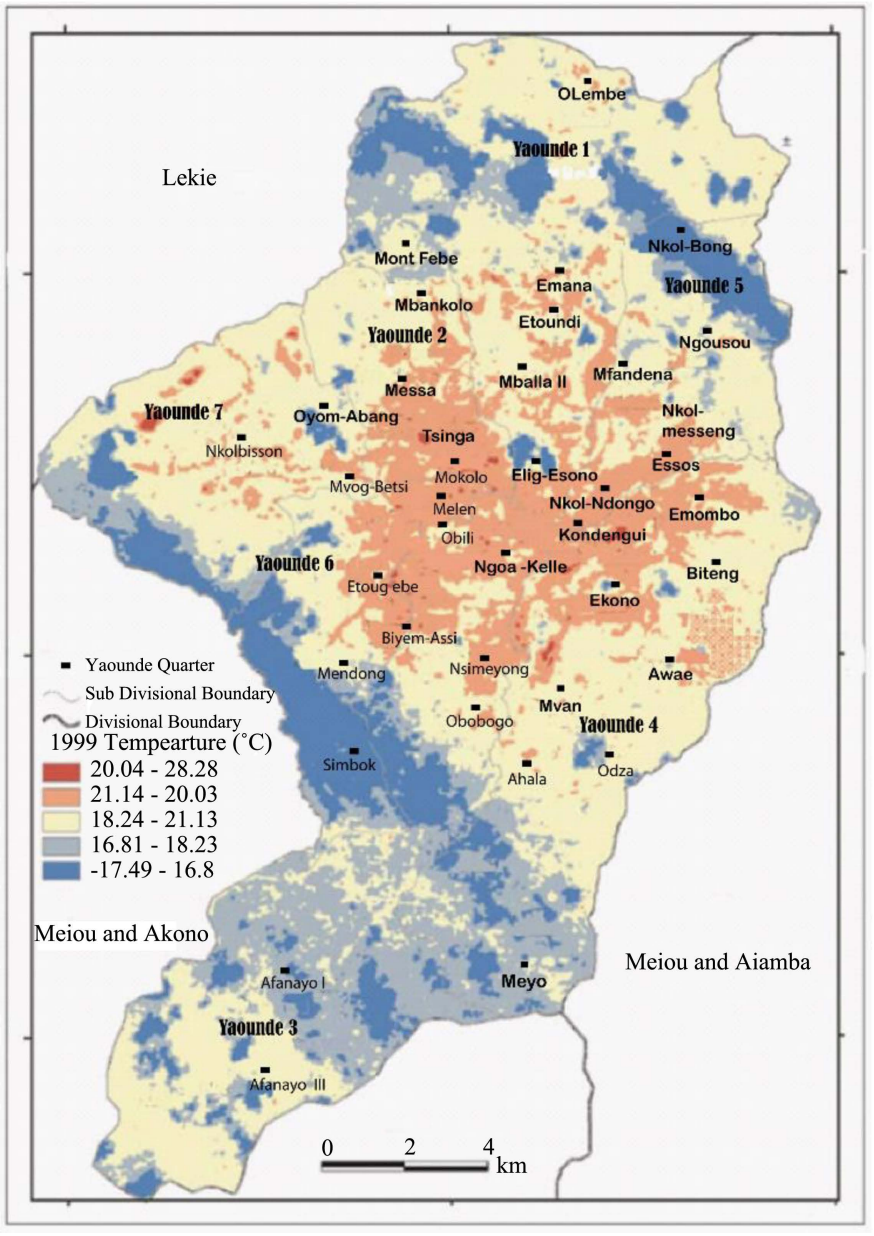

Figure 3. Situation of land use and temperature in Yaounde 1999. Source: Ojuku, 2020.

Figure 4. Population habitat and activity in Yaounde, Source: Ojuku, 2020.

activities carried out by the city dwellers and construction works undertaken by the city administration for urban development. The population exploits the forestlands for construction works and domestic energy supply. Land in Yaounde and it's neighbourhoods has been under very high demand by the population that occupies it for housing (settlement), agriculture, infrastructure development and commercial services amongst others. These anthropic activities generally lead to wanton deforestation, expansion of settlement and increase in surface temperature resulting from heat production. The nexus between deforestation, activity development and temperature rise are visible and important in understanding urban growth and extension. By determining the buildup surface using the Iron Oxide Indice (IOI) from the application of remote sensing, a relation is seen between urban heat islands and urban expansion (Figure 3).

Between 1999 and 2018, the vegetation cover of Yaounde reduced by 60 percent (two-third) in favour of population constructions. The urban build up space within this period doubled. This vegetation loss and increase in settlement have influenced the temperature change observed (Figure 5 and Figure 6).

4.1.2. Population Increase and Development

Apart from the evolution in vegetation and build up space, the population of Yaounde has also changed with implications on activities and services that influence surface temperature. According to population census data, the population of Yaounde has increased by almost 9 folds in 30 years. In 1976, it was 313,706 inhabitants, 649,252 inhabitants in 1987, 1,817,524 in 2005 and 2,765,568 inhabitants in 2015 (BUCREP, 2010 and projections). The density of population in the Centre Region has evolved from 17.1 in 1976 to 24.0 in 1987 to

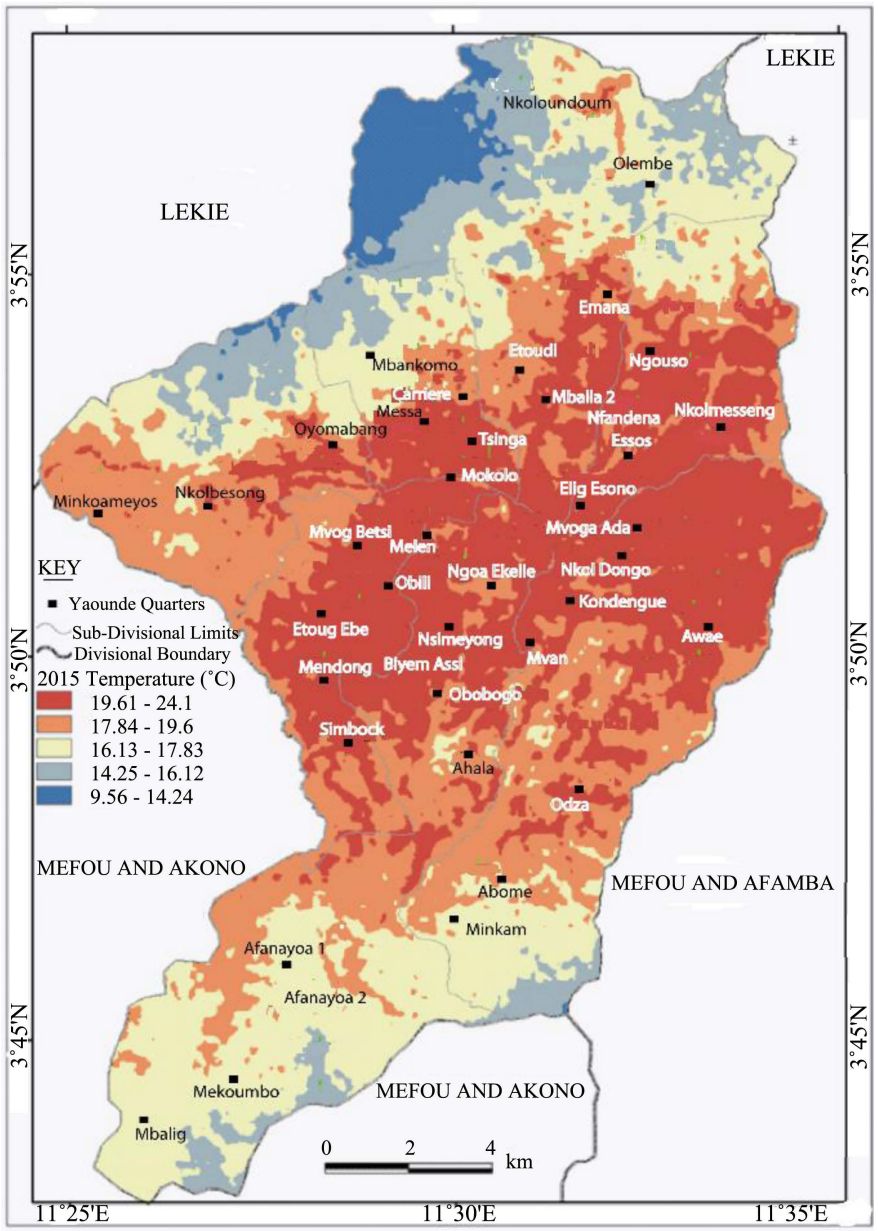

Figure 5. Situation of average temperature in Yaounde, 2015. Source: Ojuku, 2020.

44.9 in 2005 (BUCREP, 2010). Similar trends are experienced in Yaounde the regional headquarter of the Centre Region. The average population growth rate increased from 6.8 in 1976-1987 to 5.7 from 1987-2005. This population growth had an impact on land use looking at the situation near that period (Table 1).

It is observed from Table 1 that the buildup space increase was remarkable in 2015. The increment moved from 33 to 53 percent at the detriment of vegetation that declined from 26 percent in 1988 to 16 percent in 2000 and further down to 13.9 percent in 2015. This is evident proof that when the population advances, the vegetation disappears. Vegetation decline has a positive correlation with water for water sources get dry and reduce with deforestation increase. Areas of

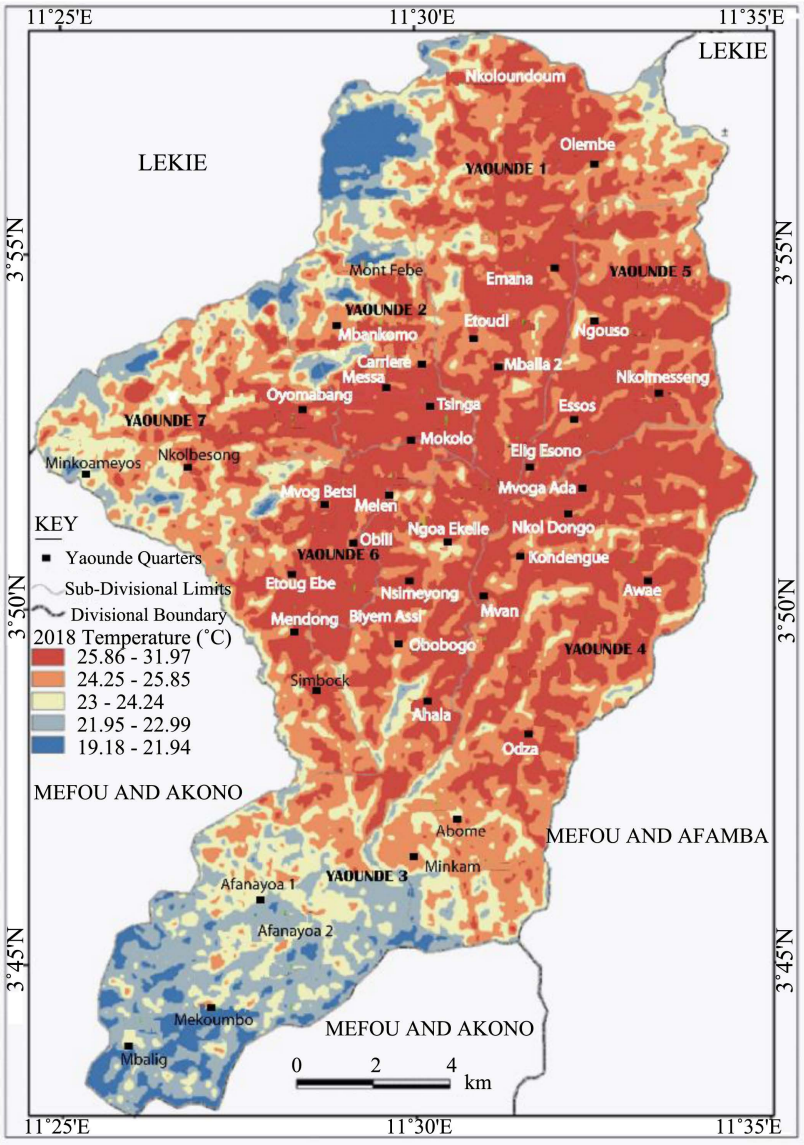

Figure 6. Situation of average temperature in Yaounde, 2018. Source: Ojuku, 2020.

Table 1. Situation of landuse in 1988, 2000 and 2015.

Land use Type/Year	Surface Area			Percentage Distribution		
	1988	**2000**	**2015**	**1988**	**2000**	**2015**
Build Up Space	6613	6296.9	15,538.9	33.9	21.7	53.6
Old Vegetation	1053	7171.8	6078.4	5.4	24	20.98
Degraded Vegetation	5099	4646.8	400.7	26.1	16.04	13.8
Young Vegetation	6641	10,744.5	3281.3	34.1	37.1	11.3
Water	84.0	109.6	63.1	0.43	0.38	0.22
Total	19,490	28,969.5	2896.5	100	100	100

Source: Choaumo (2012).

high population concentration are marked by many heats generating development activities and services (Figure 7). They include commercial buildings and activities (market places, banks, hotels, bakeries and restaurants, super markets, industries, transport agencies, motor parks and garages, weathering and construction places), public services (ministries and embassies with their buildings, equipment and parking), leisure grounds such as stadia and their parking lots and pavements, Schools, health and religious centres. The large number of service vehicles in these service places also produce a lot of heat that influences surface temperatures.

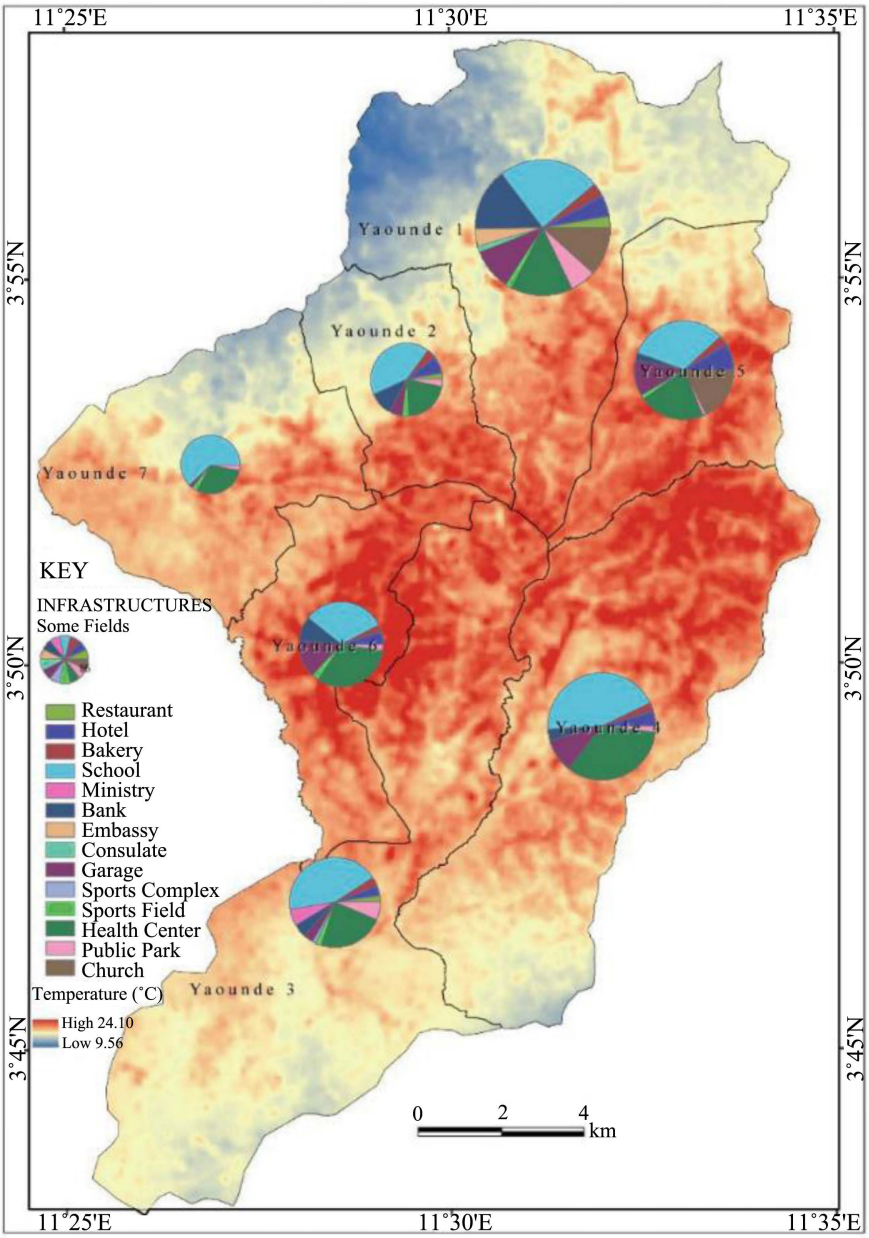

Figure 7. Distribution of temperature and activities in Mfoundi division. Source: Landsat image 2015, MINEPAT data, Fieldwork 2020.

As seen on Figure 7, development activities, equipment and infrastructures are many in the areas of high temperature and lower in the peripheries having more green spaces (vegetation, agriculture). Yaounde 1 district area has the highest number of activities. It is the area of the city that has a high concentration of activities. Yaounde 1 is closely followed by Yaounde 4 and 5 municipalities which are considered as the Central Business District of the town. Next, we have the Yaounde 6, 3 and 2 district areas. It is in these parts of the town where much of the dynamic Anglophone communities, Bamileke groups, populations of Northern Cameroon origin and other recent migrants live (Figure 9). These populations are very dynamic and industrious. They have implanted many business ventures, cottage industries and development activities that have modernized these municipalities and eliminated the remnants of vegetation and green spaces that were found in these parts of Yaounde city. Many schools, health services, hotels, petrol pumping stations, motor garages and parks, snacks, markets and drinking parlours, cultural halls have been established by these populations in Yaounde 6, 3 and 2. These installations generate a lot of heat. The establishments are densely concentrated, and their surfaces paved which cumulate much heat that increases ambient temperature especially in the dry season. Studies on Urban Heat Islands in South East Asia have shown similar conclusions. According to Ranagalage et al. (2017), Colombo which is the main commercial metropolitan in Sri Lanka, have had higher temperature increments and thermal discomforts inside the city with continuous development of the area. Finally, we have Yaounde 7 area which is being colonized rapidly by population, settlement and activities. It is in this area that many of the hilly landscapes, green spaces, agricultural institutions, farmlands and vegetation thrives. The hilly nature of the land act as an impediment to rapid urban build up (Ojuku & Mengue, 2017; Tchindjang et al., 2020). Here remnants of vegetation are being colonized by human activities (agriculture and habitats) are very visible (Figure 8 and Figure 9).

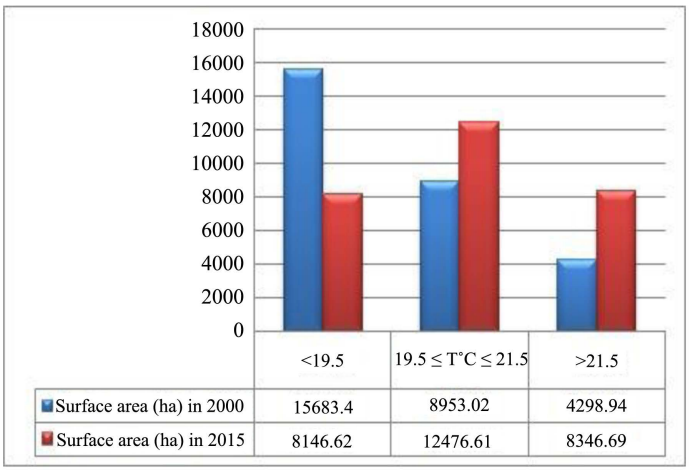

Figure 8. Evolution of surface area temperature from 2000-2015 in Mfoundi Division. Source: Ojuku, 2020.

Figure 9. Partial view of buildup space in Mendong and Simbock in Yaounde 6. Note the hills and vegetation "A" in areas facing Yaounde 7 in North of the photo. Source: Ojuku, 2020.

As the result of this work portrays (Figure 8), in the year 2000 when the vegetation cover was 58 percent for Mfoundi Division, the buildup space was smaller (15,683.4 hectares with temperature of less than 19.5˚C, 8953.02 hectares with temperature of 21.5˚C and 4298.94 hectares with temperature above 21.5˚C). Temperatures were relatively lower in 2000 than in 2015 (Figure 8). With regards to monthly distribution, temperature distribution for the months of December 1999 and 2000 was 5˚C and by 2014 it had increased three folds to 15˚C. Quarters that constituted the urban space during this period were Essos, Mokolo, Ngoa Ekelle, Mendong, Ekouno, Emombo, Ahala, Mvog-Betsi, Awae, and Nkol-messeng. These areas considered as Yaounde heat islands had the highest temperatures. Since this period, the status of the quarters has not changed as the urban core of Yaounde. The surface temperature in these quarters for 1999 and 2015 remain very high (Figure 8). In general, one observes an increase of 1˚C on average or about 0.07˚C per year, with peaks of 32˚C attend in 2015 (Figure 8). This is the consequence of rapid population, infrastructure and activity growth (Figure 9).

In 2000, the average high temperature for Yaounde urban core (heat islands) was 26.85˚C against 13.53˚C for the peripheries (Figure 6). Mvan, Ahala, Mendong, Mvog Mbetsi, Mbankolo, Emana, Ngousso, Messeng and Awae were the core quarters of Yaounde and heat Islands from 1999 to 2001. They had an average temperature of 26.85˚C. These quarters had high population concentration, dense buildings, equipment and infrastructures. Today Minkoameyos Olembe and Nkolbisong in the west, Minka Afanayoa, Mbalig, Simbock and

Mendong (Figure 9) in the south, and Awae and Odza in the East that were dominated by vegetation, farmlands and isolated settlements have also been urbanized. They are the new urban heat islands that have added in the former Yaounde urban space. In the year 2000, the average surface temperature in these new quarters was 13.53˚C. As compared to 24.7˚C in the traditional core quarters of Yaounde (urban space) at that time. The temperatures for these new urban areas formerly covered by vegetation and green spaces have increased to 15.87˚C. Today the new quarters are very congested and marked by high density of houses, public and private buildings, equipment (schools, health structures, hotels, food and super markets, and business enterprises, churches and petrol stations amongst others) and infrastructure (roads, parking lots, playgrounds, airports, railway stations, marketing spaces amongst others). One observes a net relationship between high temperature distribution and high concentration of buildings, infrastructures and services that make up the urban space (Figure 6). Quarters located at the fringes of Yaounde today such as Mbankolo and Nemayos in the south, Nsimalen and Mfou in the East, Okola and Zamagwe in the west, and Nkoumetou in the North are potential future urban heat islands of Yaounde, judging from the rapid rate of urban expansion into them. These next generation of quarters have much green spaces and forest with lower surface temperatures. In future, when these areas will be urbanized, temperatures might likely increase leading to the birth of new heat islands. Urban growth, temperature increase and development of heat island is not new in the world. Acceleration of rhythm of urbanization in the world since 1980s, have opened the way for studies on urban heat islands in the Paris and Montreal metropolitan cities (Anquez and Harlem, 2011), Nancy (Leconte, 2014), Filiatreault (2015).

In Yaounde, the extension of buildup surfaces between 1999 and 2015 have translated into a relative extension of heat surfaces in the town (Figure 6) as is the situation in other cities in the world. Computed differences in the temperature of quarters in Mfoundi Division between 1999 and 2015 shows that Mendong and Simbock located in the southern part of Yaounde that were not urbanized have experienced the highest temperature increase (7˚C) in 15 years. The factors of this temperature rise are many as will be seen in the section that follows.

4.1.3. Determinants of Urban Heat Islands

1) Population Growth

Yaounde is the second most populated and urbanized city in Cameroon after Douala. The population of the area has been increasing rapidly since 1950 and reached it first million in the year 2000. The 2021 estimate by the World Population Prospects shows that the population of Yaounde is about 4.1 million inhabitants, about 4.3% increase from 2020. Table 2 shows the changes in the population of Yaounde since 2000 indicating the total population for each year, the change within the years and the annual growth rate.

Table 2. Population evolution in Yaounde from 2000 to 2021.

Year	Population	Growth	Growth rate (%)
2000	1,35,047	72,787	5.69
2005	1,781,264	95,708	5.88
2010	2,482,205	126,364	5.69
2015	3,272,870	166,615	5.69
2020	3,992,411	169,986	4.45
2021	4,164,167	171,756	4.30

Source: Gerland (2020).

This Population growth is the engine of change in temperature resulting to urban heat islands. The more the growth of the population, the higher the demand for housing, infrastructure and services. Many houses have been constructed to meet up the increasing demand for houses (Figure 10 and Figure 11). In the construction process the vegetation that regulates high surface temperatures is destroyed and not replaced. Many houses constructed do not have green spaces. The buildings have pavements, parking lots, asphalt and concrete use for their construction and creation of roads leading to them. The surfaces of these structures needed to accommodate the growing population and activities absorb and conserve rather than reflect heat, causing surface temperatures and overall ambient temperatures to rise.

Plate 1: Urbanization of Yaounde and material for construction.

As can be seen on Figure 10 and Figure 11, several of these houses are made of concrete material and very chucked up and raised, making air circulation difficult. The heat produced by houses through heating increases the overall temperature of the surface. Vegetation in the photos is found in the outskirts of the built-up space with only isolated trees seen between buildings. The outcome of this urbanization is the birth of heat islands which have continued to expand in the Yaounde urban space since 1999 (Figure 12 and Figure 13).

Surface warming has been larger for areas that are anthropogenically developed, bare and covered with isolated remnants of forest. The geographical distribution and evolution of the dominant landcover types in Yaounde from 1999 to 2015 and correlation with surface temperature shows the urbanized areas warmer than suburban areas and wetlands covered by vegetation and croplands. The urban impact is thus visible.

The urbanized quarters show a larger trend of surface warming than green cover lands (agricultural areas, woodlands, home gardens, public ornamented spaces).

2) Expansion of human activities

Agricultural activities, residences, and business enterprises requiring land for operation have expanded in Yaounde. Encroachment of human activities into

Figure 10. Partial view of Yaounde 6 urban Area and cloudy weather in the neighbourhood covered by vegetation. Source: Ojuku, 2020.

Figure 11. Chucked up buildings with concrete material that conserve heat at Simbock quarter. Source: Ojuku, 2020.

forest lands have led to the artificialization of the urban landscape with the emergence of new quarters. Several buildings for habitation and businesses have been constructed and equipment installed (Figure 14 and Figure 15).

Plate 2: Forest colonization by urban settlement and development infrastructure.

In these urban fringes, woodlands that contribute as carbon sinks and reduce surface temperatures have been cleared and replaced with food crop farms,

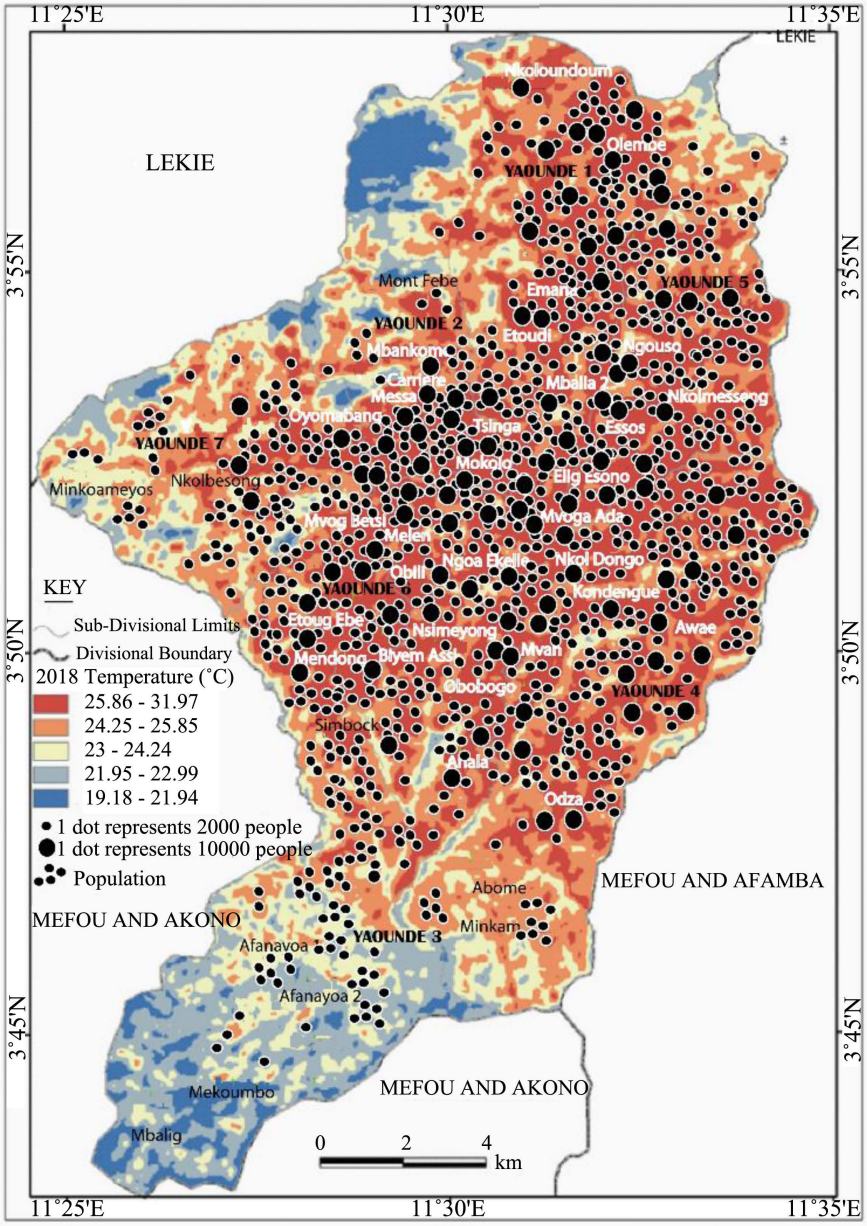

Figure 12. Situation of surface temperature and population distribution in Nfoundi. Source: Ojuku, 2020.

fishponds and poultry farms. The zone of activities is located preferably in the East and Southwestern part of Yaounde metropolis where most of them are concentrated in the urban tissue of the five districts of Yaounde. In relation to the residential area, activity zones are concentrated at 500 meters each way along the main road network.

Analysis of density of occupation of space showed some dynamics. Urban concentration reduces as the town progresses to the periphery. At a kilometer buffer from the heart of the town, it is observed that the urban perimeter forms a compact of 0 to 3 kilometers. From 0 - 2 kilometers of this buffer, the urban

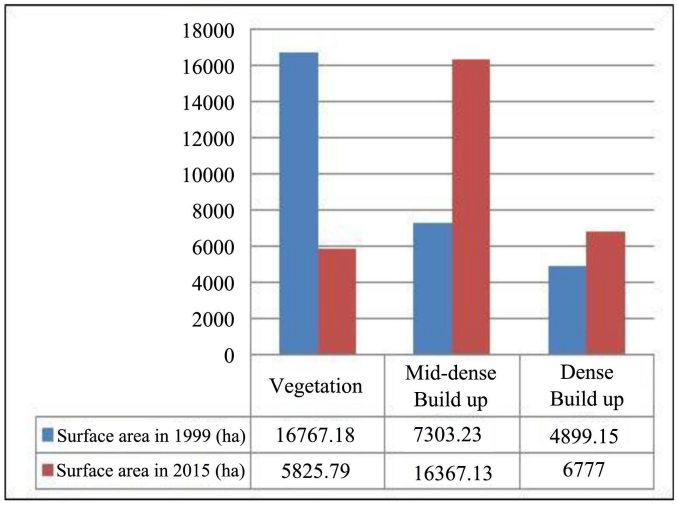

Figure 13. Evolution of surface area temperature from 2000-2015 for Mfoundi division in 2018. Source: Ojuku, 2020.

Figure 14. A build up space with roofing material that retains heat. Note the forest land invaded by buildings at Eloundem-Mbankomo. Source: Ojuku, 2020.

Figure 15. A structure under construction with concrete material. Note the building surroundings all paved with heat conservers. Source: Ojuku, 2020.

space attends 100 percent as against 90 percent 3 kilometers away from the centre. Progressively away from the nuclei, the urban space reduces to 70 kilometers at a 4 kilometers distance and 50 percent at 5 to 6 kilometers and finally 10 percent at a radius of 19 kilometers. The urbanized areas correspond to areas of high surface temperatures.

3) New Development projects

The city has benefited from several infrastructures created by the Cameroon government and foreign partners as a result of its political, economic and socio-cultural significance. In the already overcrowded planned and unplanned city neighborhoods where large populations live and carry out diverse activities, many development projects are ongoing that provide many employment opportunities. These are: football stadia and pitches such as that at Olembe and its annex training ground; the CEMENCAM factory and Dangoute cement depot at Nemayos; the Nsimalen-Yaounde new motor way; the Mfoundi river valley enlargement project; companies and supermarkets such as Santa Lucia, Maima and Dovv (one of its building under construction collapsed on the 19 of December 2019 killing four workers, wounding 12); weighing stations at the town's gateways; low cost houses constructed to accommodate civil servants, public and private real estate businesses amongst others. These development packages have modernized the town leading to population growth and expansion into the outskirts (suburban areas) of Yaounde for settlement. The occupation of peripheries has further increased deforestation due to agriculture and commercial activities, construction of habitats and infrastructure that produce bare and tarred surfaces. These transformations conserve heat and increase the surface temperatures. The paved surfaces of these development infrastructures have a low albedo, absorb solar radiation as heat, are impermeable and marked by high water runoff redirected to streams rather than being absorbed by plants and soils to cool the areas through evapotranspiration or evaporation. Heat islands have developed with negative outcomes on the city.

4.1.4. Implications of Urban Heat Islands on Yaounde

Heat islands as an indicator of urban growth have many implications on the Yaounde Urban space. These outcomes are seen on health, nutrition and goods preservation.

1) Health Implications

Rising temperature and uncertainties in the city of Yaounde has been a major factor of human health vulnerability. Coping with such variations have been a challenge to the urban population faced with emerging diseases. Malaria diseases cases have increased. This aggravates the risk of heat related mortality associated with climate variability. Wealthy households and public service centres well equipped with air conditioners and refrigerators are perhaps the less prone to high temperature induced risk and uncertainties. The low-income groups are the most vulnerable in Yaounde. Many of the poor cope by purchasing fans, spend-

ing more hours outdoor, sleeping on the floor or passing their nights with doors and windows opened to abet the effects of excessive heat. More of the victims of rising temperature live in chucked up houses without green spaces and gardens, unhygienic surroundings, haphazard buildings without respect of urban plans and building norms that require opened spaces in home surroundings. Under such living conditions many are exposed to mosquito bites and the resulting malaria which remains the most fatal disease in the tropics. Also, heat islands in Yaounde contribute to higher daytime temperature which reduced nighttime cooling and higher air pollution levels. This condition contributes to heat illnesses such as respiratory diseases, heat cramps, general discomfort and in some situations heat stroke and headaches (Giguere, 2009). The high concentration of building on the hilly terrain of many quarters of Yaounde makes water circulation difficult after heavy rainfall. Floods and pollution become a problem. Waste is highly lithered around homes, roads and water corridors that are a health hazardous (**Figure 16** and **Figure 17**).

Figure 16. A designated waste collection point at the Biyem-Assi neighbourhood. Note overfilled trash can and overflowed waste on the ground. Also note the waste in the gutter which has blocked the drainage. Source: Ntemgweh, 2020.

Figure 17. Plastic waste pollution at Biyem Assi. Note the Caterpillars and city council workers widening the valley width to facilitate water circulation. Source: Ojuku, 2020.

Populations living in heat islands are highly vulnerable to the urban problems highlighted (Figure 18).

As seen on Figures 16-18, quarters such as Biyem assi, Medong, Nsimeyong, Ako Ndoe, Mimbouman, Nkolmesseng, Oyum Abang, Nkolndongo, Ntsinga Oliga are the most vulnerable. The populations of these quarters are large and the urbanized space very high as compared to that of suburban areas such as Afanayo-Efoulan, Meyo, Nkoloudom, Nkolbisong, Ngoa Ekelle, Cite Verte that has remnants of vegetation and green spaces. Vulnerability generally reduces from the centre to the peripheries. Figure 17 shows plastic bottles disposed from households and public places transported after heavy rainfall and floods into stream courses. These plastic bottles have accumulated and get stocked along stream banks and valleys in areas of dense settlements. The waste bottles are being cleared using a caterpillar by the Yaounde 6 city council authorities and the water course being widened to ease circulation. According to Ntemngweh (2022)

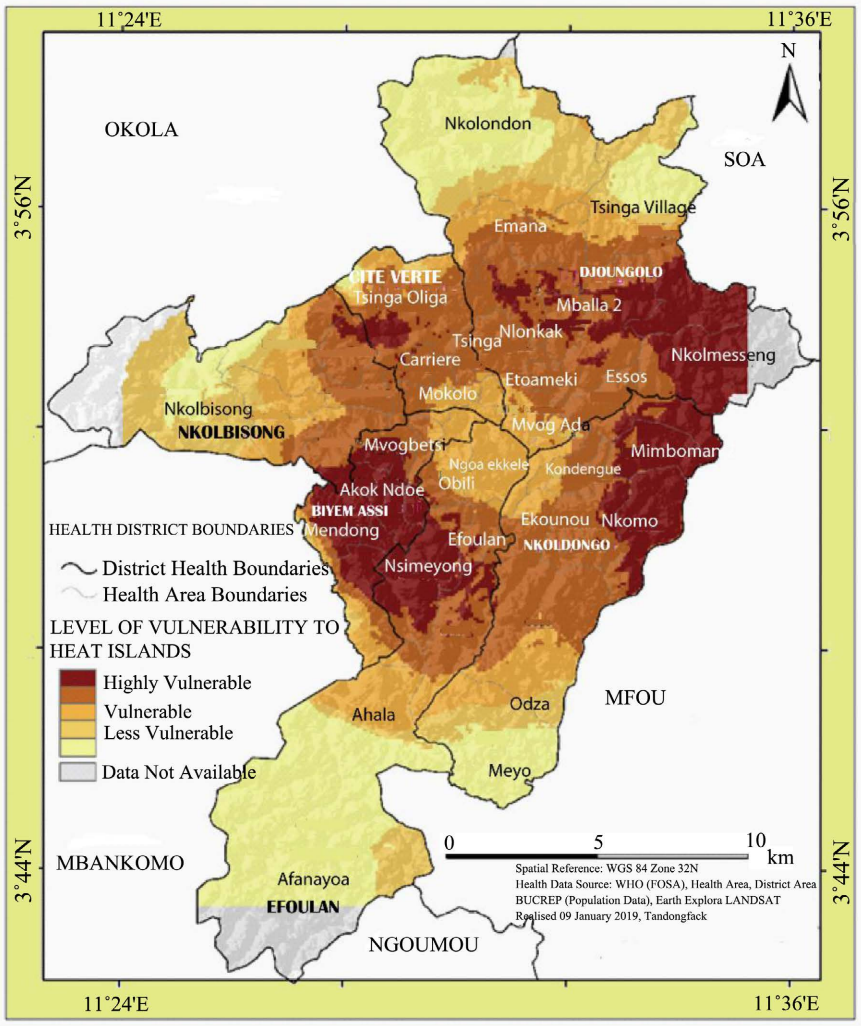

Figure 18. Map of quarters vulnerable to heat islands in Yaounde. Source: Tendongfack, 2016.

about 64% of the household interviewed disposed their waste on the ground, mainly on the streets and unused lots, 23% disposed waste into water bodies, while 6% either paid private waste collectors to collect their waste or they treated their waste by themselves (burning and converting some to compost).

Heatwaves are also becoming a health hazard. Average daytime temperature is rising, as seen on analysis of satellite images used for this study. Many people in densely settled places of Yaounde without green spaces are obliged to drink large quantities of water, shelter under buildings, ventilated houses and workplaces, consume cold drinks and take a bath several times per day to avert the situation. Several people have been victims of heat cramps, sleep deprivation with risk of mortality (Besancenot, 2002).

2) Food and Nutrition

In Yaounde, most lands used for food production in suburban areas have been replaced by buildings, urban equipment and infrastructure. Urban agriculture is on a decline following the reduction of croplands. Food security is at stake as urban food production has reduced. This has negative implications on human health as hunger and poverty is increasing. Gardens in home surroundings are also suffering the effects of excessive heat. However, many Yaounde city dwellers exploit heath islands effects to preserve foodstuff such as maize, groundnuts, onions, beans and other cereals and tuber crops from perishing. These foodstuffs are dried on house roofs, pavements and other platforms during sunshine.

4.2. Discussion

The disappearance of vegetation and failure to invest in the creation of green spaces contravenes the eleven UN development goal. This objective target rehabilitation and planning of towns and other human establishments in a way that can offer employment opportunities, basic access to energy, housing and transport services, public spaces amongst others to the population. Target seven entitled access to green spaces and public places stipulates that by the year 2030 everybody especially women, children, physically disable persons and the aged should have an assured access to these places. This is a concern in Yaounde with its rapid population growth and pressure on resources and the environment. The surface temperatures of the town are rising rapidly marked by high density and episodes of extreme heat reported in various quarters, atmospheric pollution common, levels of dust very high in the dry season in many surrounding neighbourhoods. Between 1988 and 2021, the urban space has increased by over 75 percent which correspond to the arise in surface temperatures and birth of heat islands. Build up agglomerated space represents about 97 percent of this extension. The rest of the artificial space is represented by roads, road junctions and round about as seen in the satellite images treated. The resolution of the images used could not permit a detail characterization of the buildup space into residential, artisanal, industrial and recreation surfaces. While this space has tripled in the southern of Mfoundi, in the north it has doubled along the road axis and

swampy areas faced with a hilly topography.

Green spaces creation are excellent carbon sinks faced with the ailing situation. According to the world health organization, an urban green space of 100 m^2 can contribute to reduce 1.8 ton per year of green gases. Also, it has been observed that replacement of artificial surfaces with vegetative surfaces comprising shrubs, grasses and trees, can reduce average temperature by 7˚C (Rogan et al., 2013). Dust emitted by 15 vehicles can be eliminated by 100 m^2 of greenery as the green leaves of plants of harmful particles reduce ambient temperature by 1˚C. Urban core and periphery difference in evapotranspiration is a determinant of this rising surface temperature and warming. This necessitates strategies to put in place to increase the green cover of the town to cool the city of Yaounde face with the magnitude of urban heat Island. Urban planners should consider protecting remnant forest patches on the hills and slopes of Yaounde, wetland corridors and home surroundings as this will provide ecosystem services to town, its population wellbeing and regulation of the rising surface temperatures.

Also, new building codes should be put in put in place and reinforced. These codes should set norms for eco-buildings. A house, equipment and infrastructure that generate health should have green spaces that act as carbon sinks and permeable pavements to regulate excessive heat. Promoters should be compensated for implementing excessive heat mitigation practices and defaulters taxed. This will reduce urban head islands effects.

It was highlighted that the rapid growth of economic activities, domestic industries, and construction works were responsible for production of urban heat islands in Yaounde necessitating their control. These activities are vital for urban development but must however be carried out with consideration for environmental protection. In some countries to prevent the growth of heat Islands, green rooftops, construction of greyish road surfaces to replace asphalt or tarred surfaces have been done (Tomlinson et al., 2011). In Yaounde, it will be more profitable to invest on green space production. This is because the trees or plants can easily grow considering that the town is located in a tropical rain forest ecological zone where water is abundant and soils favourable for luxuriant growth. Planting trees in public places, homes, school premises, streets, parks etc as is the current practice is good. While promoting the environment and climate change combats, this practice will help create jobs and income to the people promoting these activities. The trees will also absorb the pollutant gases and prevent soil erosion, promote ecotourism, embellish the town amongst others. This will make Yaounde sustainable and a better place to live in.

5. Conclusion

In this study, there was evidence that the temperature of Yaounde has increased exponentially over the years as a result of heat generated by human activities, solar radiation absorbed by paved surfaces and heat trapped from high concentration of buildings following difficulties of air circulation. The relief of Yaounde

influences the generation of heat islands in combination with human activities. Urban temperature rise has wider implications on global warming and has become an issue of preoccupation worldwide following its impacts on climate change. According to the 4th report of GIEC, global temperatures of the planet increased from 0.89˚C between 1901 and 2012 and are projected to rise from 1.8˚C to 4˚C in future. United States Environmental protection Agency 2010 observes that the average air temperature of towns of 1 million inhabitants stand at 1.8˚F to 5.4˚F when compared to surrounding areas. In Vijayawada town of Andhrapradesh in India, similar findings have been observed (Sundara et al., 2012). Cities in Sub Saharan Africa, Yaounde inclusive are vulnerable to climate change face with rapid population growth. Average temperatures in Cameroon increased by 0.7˚C from 1960 to 2007 (Mcsweeney et al., 2010). Green solutions need to be sorted to reduce the impacts of urbanization. It has also been discovered in this paper that a net correlation exists between temperature variation and urbanized areas. This knowledge is available thanks to data obtained due to advances in remote sensing. Contrary to the past when urbanization was determined based on population and activities expansion, Landsat images of different dates can be exploited to calculate surface temperature to identify heat islands in our cities including Yaounde. This temperature when correlated with urban activities and population data can help to comprehend the urbanization process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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