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Analysis of urban heat island effects on human health in Abidjan, Côte d'Ivoire

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Résumé

Selon la SODEXAM, la ville d'Abidjan a connu ces 10 dernières années, une augmentation de la fréquence et de l'amplitude de vagues de chaleur. Cette hausse constante de la température se traduit par des îlots de chaleur urbains (ICU). Les ICU sont des secteurs urbanisés caractérisés par des températures du sol plus élevées de 5 à 10^0 C que l'environnement immédiat. Cette situation peut avoir des effets considérables sur la santé des communautés vulnérables. L'objectif de ce projet est d'étudier les effets des ICU sur la santé des populations. La méthodologie s'appuie sur la recherche documentaire, le traitement des images de satellites, l'analyse des données d'enquêtes épidémiologiques auprès des personnes âgées, des enfants de moins de cinq ans et des personnes exerçant à l'extérieur. Les résultats de cette étude révèlent plusieurs zones à risques au ICU. Ce sont les zones de forte densité des bâtis du centre d'Abobo, la partie sud d'Adjamé, le Centre et le sud d'Attécoubé, le centre de Yopougon, les parties est et sud de Port-Bouët et enfin la quasi-totalité de Koumassi, Marcory et Treichville. Les populations habitant ces espaces à risques présentent de fortes migraines, une extrême fatigue, des coups de chaleur-corps chauds, des toux sèches, des vertiges, des pertes de connaissances et des douleurs à la poitrine. À ces signes cliniques, les populations enquêtées ont déclaré plusieurs maladies à savoir : le paludisme, les affections de l'appareil digestif, le diabète, l'affection de l'appareil respiratoire, les infections de la peau, les troubles cardiaques et les douleurs chroniques. Les prévisions climatiques prédisent de grandes vagues de chaleur en milieu urbain les années à venir, c'est pourquoi des actions doivent être mises en place par les autorités ivoiriennes pour atténuer les effets des ICU sur la santé des populations vulnérables qui y vivent.

Mots-clés : Abidjan, Îlots de chaleur urbaine, forte chauffeur, maladies, zones à risque, population vulnérables.

Abstract

According to SODEXAM, the city of Abidjan has experienced an increase in the frequency and amplitude of heat waves over the past decade. This constant rise in temperature is reflected in urban heat islands (UHI). UHIs are urbanised areas with ground temperatures 5 to 100 C above the immediate environment. This can have significant health effects on vulnerable communities. This project aims to study the effects of UHIs on the health of populations. The methodology is based on literature searches, satellite image processing, and analysis of epidemiological survey data of older people, children under five years of age, and outdoor workers. The results of this study reveal several risk areas for UHI. These are the high-density areas in the centre of Abobo, the southern area of Adjamé, the centre and south of Attécoubé, the centre of Yopougon, the eastern and southern areas of Port-Bouët, and almost all of Koumassi, Marcory and Treichville. The populations living in these high-risk areas present intense migraines, extreme fatigue, heat stroke, dry coughs, dizziness, loss of consciousness and chest pain. In addition to these clinical signs, the surveyed populations reported several illnesses, namely malaria, digestive tract diseases, diabetes, respiratory tract diseases, skin infections, heart problems and chronic pain. Climate forecasts predict major heat waves in urban areas in the coming years, which is why actions must be put in place by the authorities in Côte d'Ivoire to mitigate the effects of UHI on the health of vulnerable populations living there.

Keywords: Abidjan, urban heat islands, intense heat, diseases, at-risk areas, vulnerable population.

Analysis of urban heat island effects on human health in Abidjan, Côte d’Ivoire

Introduction

The Earth's climate is changing rapidly due to human activity. Climate models predict a rise in global temperatures of up to 4.8°C by 2100, according to various scenarios and depending on the effectiveness of climate policies (Urbinello & Künzli, 2015). Climate change is expected to cause more extreme weather events such as heatwaves, storms, floods, droughts, and cyclones due to rising temperatures (UN, 2019). According to projections by the Intergovernmental Panel on Climate Change (IPCC), higher temperatures will result in more frequent heatwaves in the future (IPCC, 2020). In Africa, the IPCC projects an increase in the number and severity of heatwaves, particularly in urban areas, due to rising temperatures caused by climate change (IPCC, 2014). According to the *Société d'exploitation et de développement aéroportuaire, aéronautique et météorologue* (SODEXAM), over the past decade the city of Abidjan has seen an increase in the frequency (more hot days) and amplitude (intensity and length) of heatwaves (SODEXAM, 2015). Constantly rising observed and projected temperatures are set to worsen the urban heat island (UHI) effect. UHIs are urbanised areas where ground temperatures are 5° to 10°C higher than in the immediate environment (Voogt, 2003; Camilloni et Barro, 1997; Charabi, 2001; Baudoin et Guay, 2005, p.1-8).

The heat generated by human activities in urban areas worsens this phenomenon. Its size and shape are influenced by multiple factors: extreme heatwaves, the city's geographical location, its spatial relationships (urban geometry), structure (division between mineral and plant surfaces) and size (surface area, density and population). (Sakhy et *al.*, 2011; Simmonds et Plummer, 2001). As Ringenbach (2004) notes, all these factors modify heat transfer. Heat accumulates and intensifies in urban areas due to radiation trapping caused by surface roughness, creating an "urban canyon" effect. Urban buildings store large amounts of heat and are subject to stronger and slower thermal inertia than in rural areas. The phenomenon of inertia is exacerbated by higher surface albedo in urban areas compared to rural areas (Aida et Gotoh, 1982).

The effects of rapid and persistent climate change on health are likely to be broadly negative, particularly for the poorest, weakest and least-prepared populations (C. Howard, P. Huston, 2019).

Although the urban heat islands (UHIs) phenomenon was first noted over a century ago, its full significance is only now coming to light. The growing number and intensity of annual extreme heat events impact people's health and well-being (Lachance, Baudoin et Guay, 2006; Gouataine et Ymba, 2019).

Urban heat islands (UHIs) pose major public health risks and affect morbidity and mortality rates of exposed populations (IPCC, 2001) by creating heat stress[1] in individuals. Extreme heat can trigger discomfort and ailments, worsen chronic conditions and cause death (Giguère, 2009). In 2003, intense and prolonged heatwaves killed more than 15,000 people in France (Cadot et Spira, 2006). Older people were hardest hit, particularly women (Besancenot, 2004). Older people are

1 Heat stress is caused by the accumulation of heat in the human body and can prove fatal.

more prone to heat-related problems, particularly because of physiological changes associated with ageing (Thibault *et al.*, 2004). This is compounded by the significant impact on health and death rates in vulnerable communities including infants, outdoor workers, the destitute, and people living in city centres and disadvantaged neighbourhoods, including an increase in mortality (WHO, 2007). Heatwaves in summer 2003 in Europe and 2010 in the Sahel caused a spike in mortality rates (Lamothe et *al.*, 2019).

According to several authors, the overwhelming heat generated by UHIs can cause weakness, loss of consciousness, cramps, blackouts and heat stroke, and can worsen pre-existing chronic illnesses such as diabetes, respiratory failure, and cardiovascular, cerebrovascular, neurological and renal diseases, to the point of causing death (Besancenot, 2002; Luber and McGeehin, 2008).

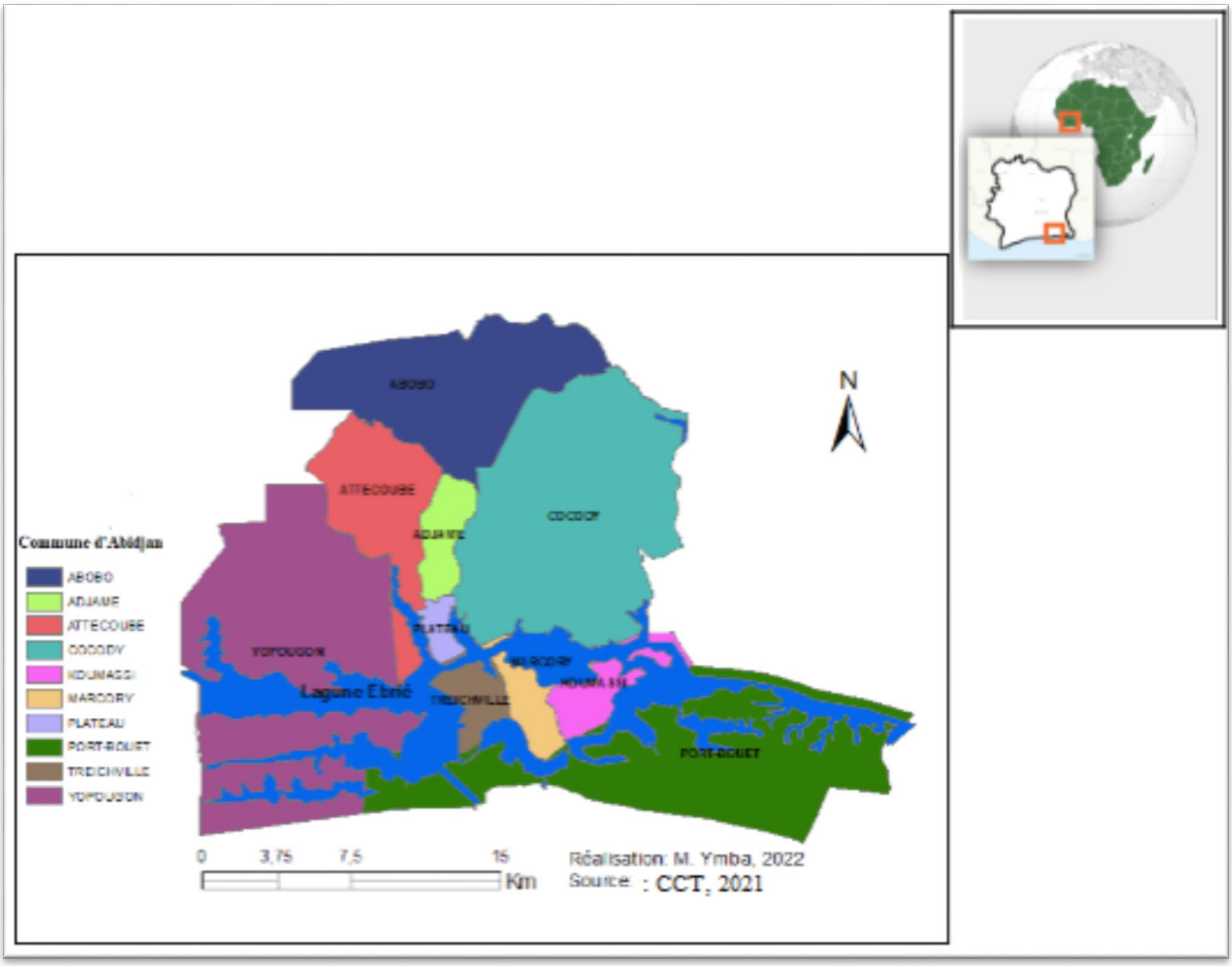
Creating and sustaining adaptation measures to safeguard public health and minimise vulnerability is crucial. The World Health Organisation (WHO) recommends health agencies and other stakeholders organise programmes to combat the effects of extreme heat and prevent the formation of urban heat islands to mitigate their adverse effects on health and well-being. Effective action requires an awareness and thorough understanding of the phenomenon. For decades, little attention has been paid to this familiar issue in Côte d’Ivoire and almost no information has been gathered on the subject. Although climate models predict a rise in the Earth’s temperature leading to more frequent extreme heat events, the authorities in Côte d'Ivoire still have a poor understanding of this threat despite the risk to health. The impact of surface temperatures or UHIs on human health and well-being cannot be accurately quantified due to insufficient evidence, with repercussions for climate change action plans and initiatives. To correct this problem, this project aims to determine the specific nature of UHIs in Côte d’Ivoire. It identifies areas at risk from the effects of UHIs in the Abidjan urban area and analyses the impact of UHI effects on the health and well-being of vulnerable populations.

Methodology

Limits of the study

The city of Abidjan is in the south of Côte d'Ivoire between latitudes 5°15N and 5°26N and longitudes 4°5W and 3°54 (see Figure 1). It is the country's largest city and the most populous in French-speaking West Africa, with 6,351,086 inhabitants – 20% of the country's total population. It is the economic capital of Côte d’Ivoire and covers an area of 422km². Abidjan has more than 280 districts, with a population density of around 15,050 inhabitants/km². The city of Abidjan is divided into two areas: "Abidjan North", comprising the districts of Plateau, Adjamé, Attécoubé, Cocody, Yopougon and Abobo, and "Abidjan South", including the districts of Treichville, Marcory, Koumassi and Port-Bouët. The Ebrié Lagoon separates the two areas. "Abidjan North" is the mainland part of Abidjan. "Abidjan South" lies between the Ebrié Lagoon and the sea. The Abidjan region lies in a climate zone covering Lower Côte d'Ivoire from the 8th parallel to the coast. It has a sub-equatorial climate. There are two rainy seasons and two dry seasons. There is intense human activity in this area and little vegetation.

Figure 1: Location of the study area



(Commune d’Abidjan / City of Abidjan)

Data

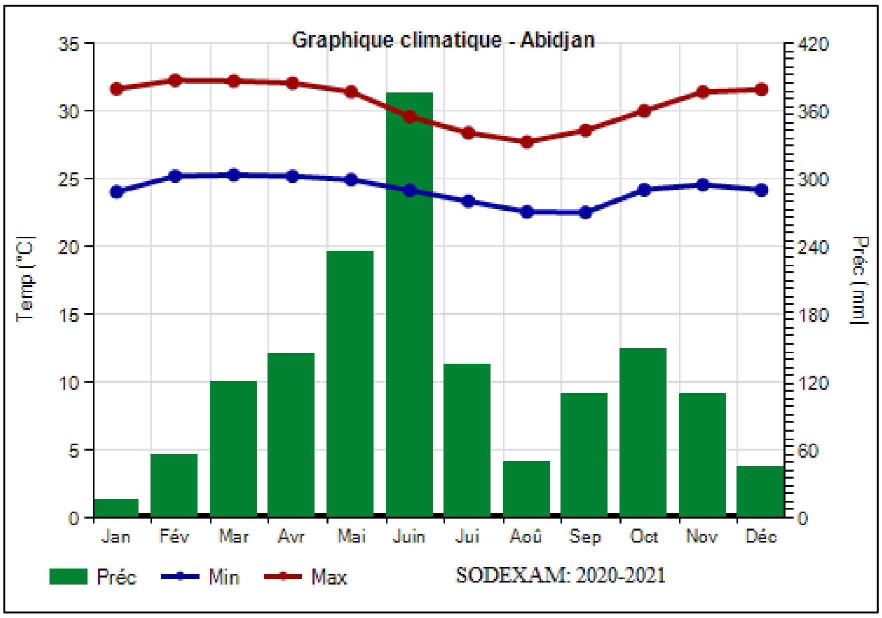
The study is based on remote sensing and climate data, health data from health facilities, and data from population health surveys. It should be noted, however, that the study began with a literature search. We consulted scientific documents, reports and government documents in libraries and used specialised search engines such as Google Scholar, Medline, BMC, Springer and Webscience and Doaj for the period 1995-2018, in French and English.

Remote sensing and climate data

Remote sensing data were downloaded from the official LANDSAT 8 satellite website via this link https://earthexplorer.usgs.gov/ for March 2021, the hottest month, with temperatures generally exceeding 34.5°C (SODEXAM, 2021). We used this data to calculate surface temperatures and identify urban heat islands (UHIs), i.e. the hottest places in the city of Abidjan with potentially harmful effects on health. This image was chosen for its availability and quality. We used Band 10 - Thermal Infrared (TIRS) 1 to study the spatial dynamics of temperatures in Abidjan.

Climate data (temperature and precipitation) were gathered by *the Société d'exploitation et de développement aéroportuaire, aéronautique et météorologue* (SODEXAM) in November 2021 (see Table 1 and Figure 2). The months studied were selected according to these climatic data values. The study was made from February to April, the hottest time of the year, and in June, the "coldest" time of the year in Abidjan.

Figure 2. Monthly variation in rainfall and temperature



Source: SODEXAM, 1991-2020

Table 1. Abidjan - Average temperatures (1991-2020)

Month	Min (°C)	Max (°C)	Average (°C)
January	24	31.7	27.8
February	25.2	32.3	28.8
March	25.3	32.2	28.8
April	25.2	32.1	28.6
May	25	31.4	28.2
June	24.2	29.6	26.9
July	23.4	28.4	25.9
August	22.6	27.7	25.2
September	22.5	28.6	25.6
October	24.2	30	27.1
November	24.6	31.4	28
December	24.2	31.6	27.9
Year	24.2	30.6	27.35

The land-use map uses the following variables: built-up areas, bare soil, vegetation, and water data derived from the research of A. Mobio et al in 2017. We used the land-use map to identify urban development responsible for microclimatic effects in Abidjan. The team processed satellite imagery to produce the 2014 land-use map of Abidjan. We identified four land-use classes. These classes correspond to variables used to describe the spatialisation of temperatures in Abidjan. They are built-up areas, bare soil, vegetation and water. Each class is composed of one or more entities (see Table 2).

Table 2. Land-use classes and categories studied

Classe	Catégoriesconsidérées
Bâtis	Les maisons (lieux d'habitation), les grandes surfaces et les édifices
Sols nus	Les parkings, les routes, les espaces libres
Eau	Coursd'eau
Végétation	La forêt, les espaces verts, les zones agricoles, les espaces boisés

Source: A. Mobio et *al.*, 2017

Health data

The health data used in this study are sourced from the Ministry of Health's Direction de l'Informatique et de l'Information Sanitaire (DIIS) health database for the Abidjan conurbation gathered between October and November 2021 and January to April 2022. They were georeferenced and grouped by referral healthcare level according to the Côte d'Ivoire health pyramid. These data relate to healthcare facilities. We also consulted the health registers of health centres for the hottest months (February, March and April) in the study area to compare the pathologies diagnosed in healthcare facilities with those reported in the study populations. Data on illnesses caused by high or perceived temperatures were collected for 2021 from the literature. We measured the following variables: consultation date, age, sex, length of residence, place of residence, symptoms, diagnosed pathology, etc.

Public health survey data

The questionnaire-based epidemiological survey was conducted from February to April (warm months) and May to June (cold months). It covered the hot zones of Abidjan and the less hot zones on the city's outskirts. We interviewed older people, women and men over 50 (age limit based on INS, 2014), children (under 5) and people working outside. We completed the survey at the end of June 2022.

To select the survey areas, we drew lots for districts in areas vulnerable to UHIs and less exposed areas. Our aim was to assess the effects of the level of exposure to UHIs.

We used quota sampling to select respondents and applied the following mathematical formula: $N = t^2 \times p\,(1-p)/m^2$ with N: Sample size, t: 95% confidence level (standard value 1.96), p: Proportion of people assumed to have the required characteristics. This proportion, varying between 0.0 and 1, is the occurrence probability of an event and m is the margin of error at (5% (typical value 0.05). Based on this definition, the number of respondents was 1,332.

Table 3. Abidjan health survey sample

	Children 6 months to 12 years		People working outside		Adults and older people		
	Girls	Boys	Women	Men	Older people > 45 years	Women 25-45 years	Men 25-35 years
Membership	135	141	141	157	175	287	296
Sex (%)	48.91	51.08	47.31	52.68	23.08	37.86	39.05
Total	276		298		758		
Total number of people surveyed	**1332**						

Source: Field survey, Abidjan, 2022

We used a questionnaire to gather qualitative and quantitative data on demographic and socio-economic characteristics (age, sex, level of education and literacy, employment, etc.), mode of transport, place of residence, heatwave perceptions, reported morbidity, type of medical consultation, etc. Some people refused to answer our questions in the field. Twenty per cent (20%) of people refused, i.e. 266. The final sample therefore consisted of 1,066 respondents.

Methods

Calculating surface temperatures

This method is based on the work of A. Mobio et al, 2017. The data was processed using raw satellite imagery integrated into GIS software. To transform spectral values into surface temperatures, we used several algorithms to transform the surface emissivity values of the thermal interval into temperature in degrees Celsius (S. Ariane, 1991). Landsat satellite sensors (TIRS-1) collect temperature data and store them as digital values or Digital Data (DD). These digital numbers are then converted into surface temperature (degrees Kelvin). The data is converted in three steps:

- First, the DD are converted into spectral radiance using the following equation:
  - DD = (CVR1 - compensation) / gain **(1)**
  - DD: digital data or digital numbers
  - CVR1: radiance value
  - Compensation: polarisation value in a specific band
  - CVR1= ((LMAXλ-LMINλ) / (QCALMAX-QCALMIN)) × (QCAL-QCALMIN) +LMINλ **(2)**
  - QCAL: digital number
  - LMAXλ and LMINλ: spectral radiance scales.
  - QCALMAX and QCALMIN: pixel values.

- Once the digital numbers of the thermal bands had been converted into radiance, we applied the inverse of Planck's law to extract the temperature in degrees Kelvin (T °k). The transformation equation is:
  - T (°k) = K2/ln (K1×ε / CVR1 +1) **(3)**
  - T (°K): temperature in degrees Kelvin
  - This temperature is converted into degrees Celsius using the equation:
  - T (°C) = T (°K) – 273 **(4)**

After extracting the surface temperature, five temperature levels were determined to produce the temperature spatialisation map. The aim is to distinguish the cooler from the warmer areas. We used ArcGIS's Jenks method to determine the temperature levels. Jenks' method is an algorithm that reduces intra-class variance and maximises inter-class variance. According to the number of classes specified at the outset, this method identifies the classes containing the most homogeneous individuals (close values) and those most distinct. If the distribution contains breaks (areas of low value density), these will necessarily be detected by the Jenks' method, a rigorous variant of the well-known "natural breaks" method (Gosselin., 2013). The tool used to measure this homogeneity is Jenks Natural Breaks, which is the ratio of the sum of the variances of each class and the number of classes (Jenks Natural Breaks = (sum of the variance of each class) / number of classes).

Field data processing

The completed questionnaires for the cross-sectional household survey were quality controlled. The data were entered into a data input mask developed in Epi Data and transferred to SPSS and Excel for statistical processing.

The analysis strategy involves two interconnected stages that provide complementary information. We began by carrying out a general analysis of the most common illnesses and treatment practices in each neighbourhood. We made correlational analyses to understand the major implications of UHIs and/or other factors for the health of populations. We assessed the significance of statistical relationships by subjecting their assumed consequences to Pearson's Chi2-Test. Pearson's P-value indicated the degree of significance of the associations. We also produced thematic maps of morbidity using GIS software.

Findings

Spatial distribution of surface temperatures in Abidjan

We reached our findings on the spatial distribution of surface temperatures by calculating the surface temperature using OLI Landsat thermal bands for bands 10 and 11 in ArcGis. Figures 3 and 4 show that UHI formations are concentrated in the city's central areas. These areas correspond to the core of Abidjan. The highest temperatures are found in dense urban centres. They include the heavily urbanised central districts: the central area of Abobo, the southern area of Adjamé, the central and southern areas of Attécoubé, the centre of Yopougon, and the eastern and southern areas of Port-Bouët. As shown in Figure 5, these districts have a strong human footprint, marked by high levels of human activity and a lack of vegetation.

Figure 5 shows four (4) building density classes: high, medium, low, and zero. The most densely built-up areas are the centre of Abobo, the southern area of Adjamé, the centre and south of Attécoubé, the centre of Yopougon, the eastern and southern areas of Port-Bouët and almost all of Koumassi, Marcory and Treichville. Figures 3 and 4 show that these areas correspond exactly to UHI risk areas. The areas with medium and low building density are the west of Cocody, the extreme south and centre-north of Abobo (around the area with high building density), the centre-west and south of Yopougon (around the area with high building density), the south-east of Attécoubé, the Plateau, the extreme north and south of Koumassi, Marcory and Treichville and the eastern part of Port-Bouët. Zones with zero density correspond to vegetation mainly at the extremities of the city of Abidjan, i.e. the north of Port-Bouët, the eastern part of Cocody, the north of Abobo, the northern part of Attécoubé (Banco forest) and the north-western and southern parts of Yopougon. The risk of exposure to UHIs is low in these areas. The lack of vegetation in these areas due to densification and urbanisation makes them even more vulnerable.

Figure 3. Temperatures recorded in March 2021 in Abidjan

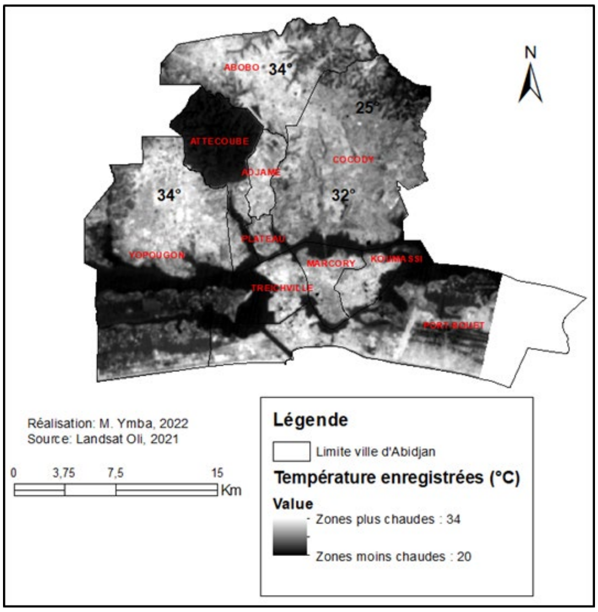


Figure 4. Identification of UHIs in the city of Abidjan

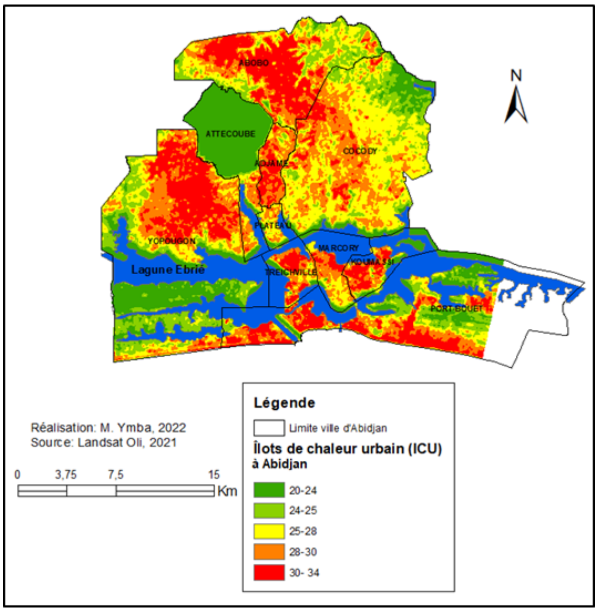
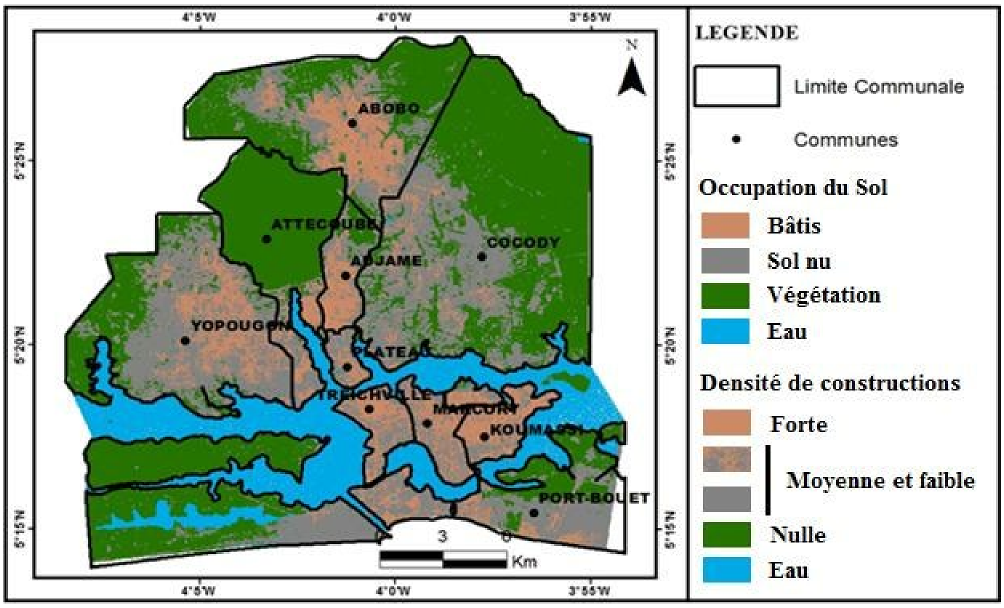


Figure 5: Land-use map of the city of Abidjan



Source: A. Mobio et *al.*, 2017

Vulnerability of populations to high surface temperatures in the city of Abidjan

The surface temperature identification map (4) highlights three microclimatic zones in Abidjan. These areas have temperatures between 0 and 25°C; 25 and 30°C; and over 34°C. Areas above 34°C are found in almost all Koumassi, Marcory and Treichville districts. This temperature range is found in Abobo's central, southeastern, and some western areas. Temperatures were very high in the central and southeastern areas of Yopougon. High temperatures occur in the southern half and north-west (Adjamé) of Attécoubé and Adjamé. In Cocody, these temperatures are focused in small areas scattered throughout the centre. High temperatures are recorded across almost the whole southern sector of Port-Bouet. The whole of the large southern sector of Cocody falls within a temperature range of 22.5 and 25°C. These temperatures are found in the west of Abobo, in the centre-west and south of Yopougon, in the south-east of Attécoubé, in the Plateau, in the northern and southern extremes of Koumassi, Marcory and Treichville and the north-east of Port-Bouët. The surveyed populations who complained the most about aches and pains caused by high temperatures (see Figure 6) were identified in these areas. The main complaints were severe migraines, extreme fatigue, heatstroke, overheating, dry coughs, dizziness, loss of consciousness and chest pains. These clinical signs are characteristic of the physiological state of patients who consult medical professionals during rising temperatures (WHO, 2018). Superimposing the UHI and perceived pain maps shows that over 27% of respondents face discomfort and suffering at these times, which are challenging in addition to their everyday activities. This explains the fears the population expresses during extreme heatwaves (see Figure 7).

Figure 6: Spatial distribution of surface temperatures and pain perceived by populations

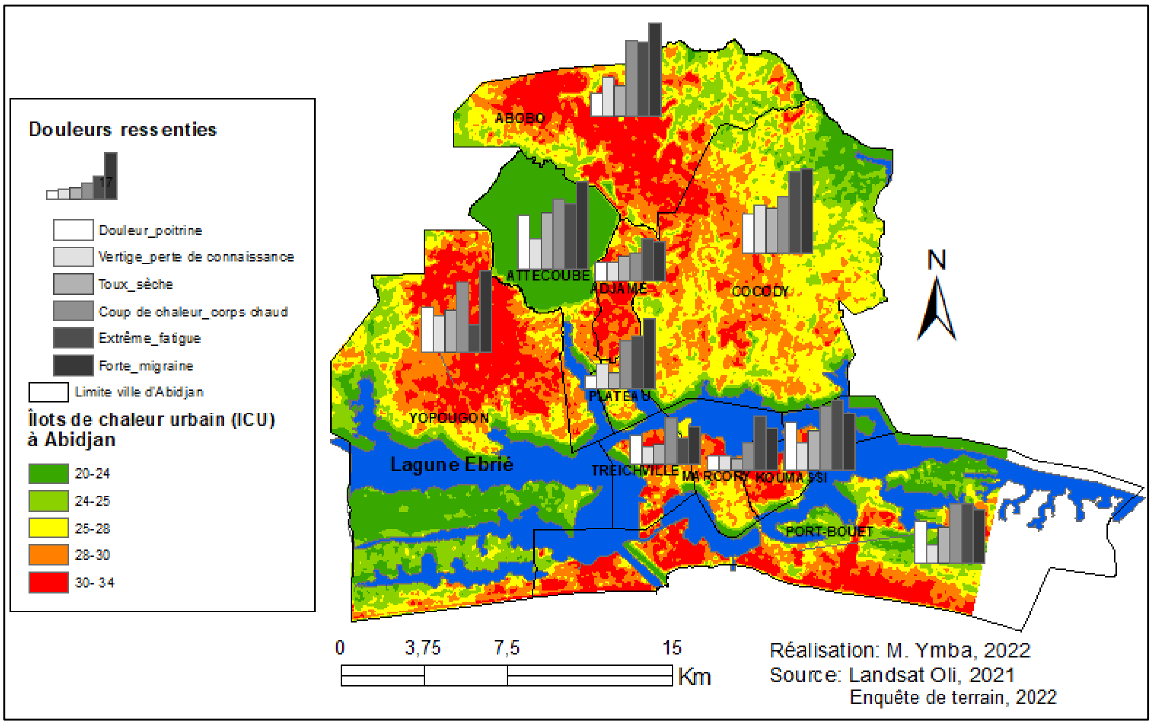
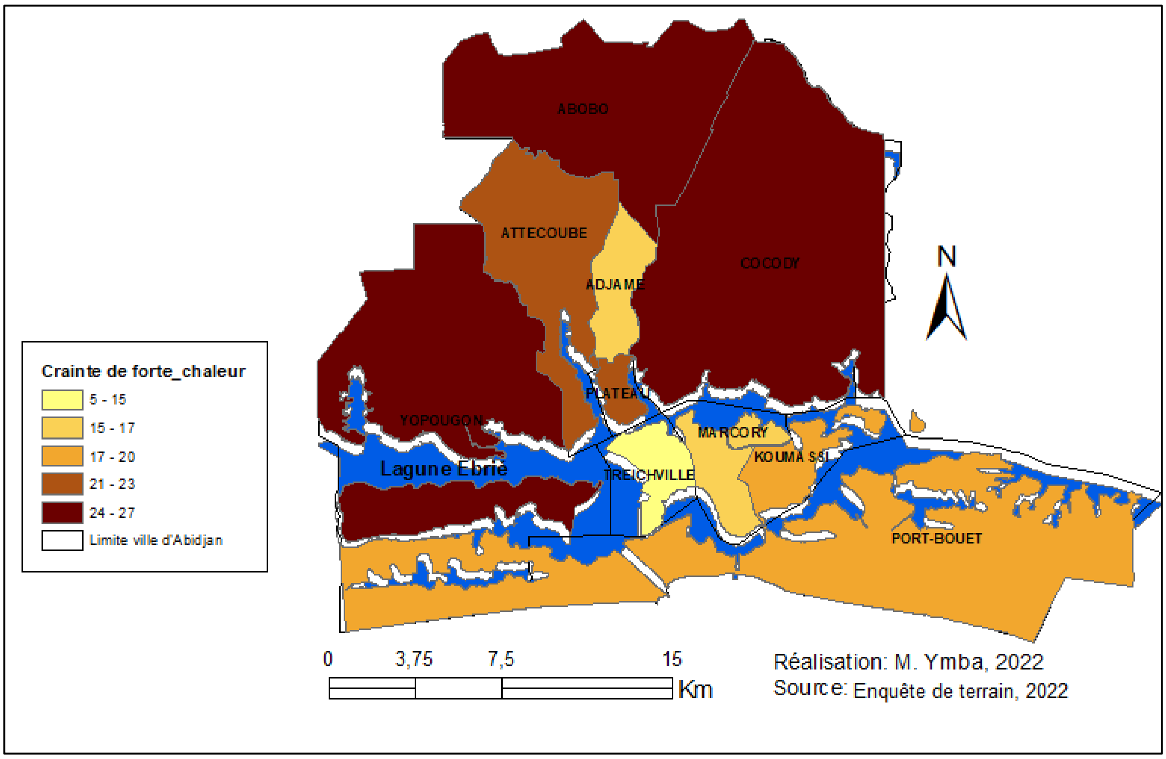


Figure 7. Fear of heatwaves by surveyed area



Impact of surface temperatures on the health of surveyed vulnerable populations

Disease and illness in children

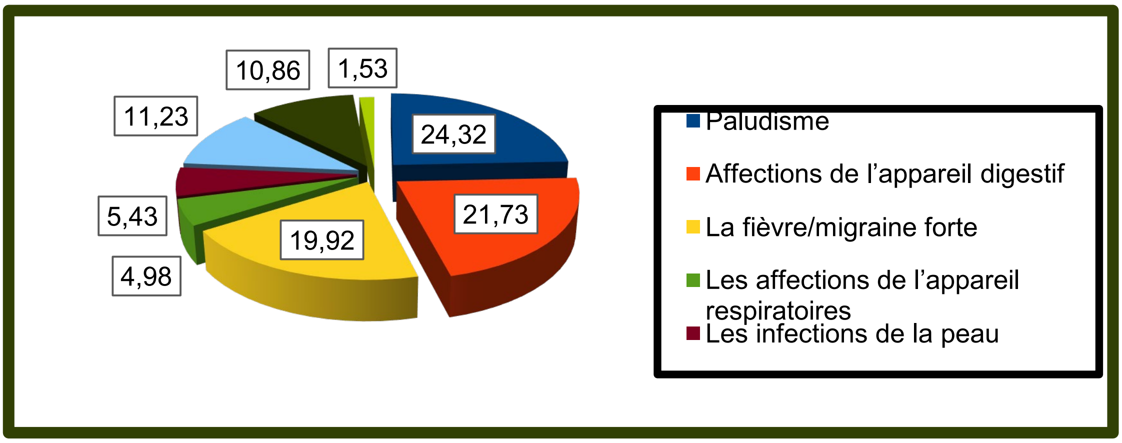
When asked: "Did you have a health problem in February and March?"[2] 42% of children aged 6 months to 12 years (or their carers) replied yes. Out of the 276 individuals who had experienced illness, the most frequently reported conditions were malaria (25%), digestive tract disorders (22%), high fever/migraine (20%), pain (11%), cough (11%), skin infections (5%), respiratory tract disorders (4%) and heart failure (2%).

Malaria was the most common disease recorded in the survey (see Figure 8). This should be understood as seasonal. Bio-ecological conditions favour the development and spread of malaria-carrying mosquitoes (anopheles), especially during intense sunlight.

Children between 6 months and 2 years are also most susceptible to health issues ($p<0.0001$). Boys are more likely to fall ill than girls, although no significant difference exists. Health problems are generally less likely to be reported as the child ages.

Reporting a health problem is associated with perception of health or well-being. Children who reported poor health were likelier to have experienced disease or illness ($p<0.0001$). Paradoxically, a child regularly monitored by medical professionals for a chronic health problem, and therefore in poorer health, was less likely to report an illness event at the time of the survey (21% compared with 31.1%).

Figure 8. The most common illnesses among children during heatwaves



Source: Field survey, Abidjan, 2022

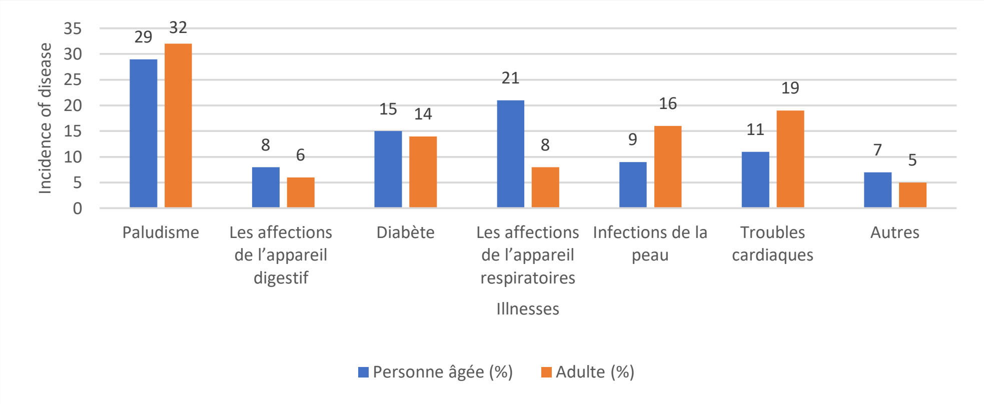
Disease and illness in adults and older people

During February and March, 32.3% of older people and 42% of adults had a health problem. Figure 9 outlines the main health problems older people and adults reported during our visit. Malaria is the most common health problem among adults (32%) and older people (29%). Digestive and respiratory tract disorders are less common in adults (6% and 8% respectively), but slightly more common in older people (8% and 21%). At the same time, diabetes, skin infections and heart

[2] February and March are the hottest months in Abidjan.

problems are more common among adults (15% and 19% versus 9% and 11%). The health problems identified are more widespread and varied in adults. Skin and eye problems, coughs, cholera, reproductive tract disorders and heart or kidney failure were more common in the 'other' category in adults. Adults reported more health problems during the extremely hot season than during the rainy seasons.

Figure 9. The most common illnesses in older people and adults



Source: Field survey, Abidjan, 2022

Illness and disease in people working outside

During February and March, outdoor workers reported health issues during intense heat. Malaria is the most reported disease (31%) across all studied population groups. However, outdoor workers experience high rates of diabetes (14%), chronic pain (9%), and heart or kidney failure (10%), which are typical heat-related illnesses. People working outdoors are much more vulnerable to UHIs since they report more health problems in the dry season than in the rainy season.

Table 4. The most common illnesses in people working outdoors

Illnesses	Relative frequency among older people (%)
Malaria	31
Digestive tract disorders	8
Diabetes	14
Respiratory tract disorders	13
Skin infections	9
Heart problems	10
Chronic pain	9
Other (eye diseases, cholera, reproductive tract disorders)	6

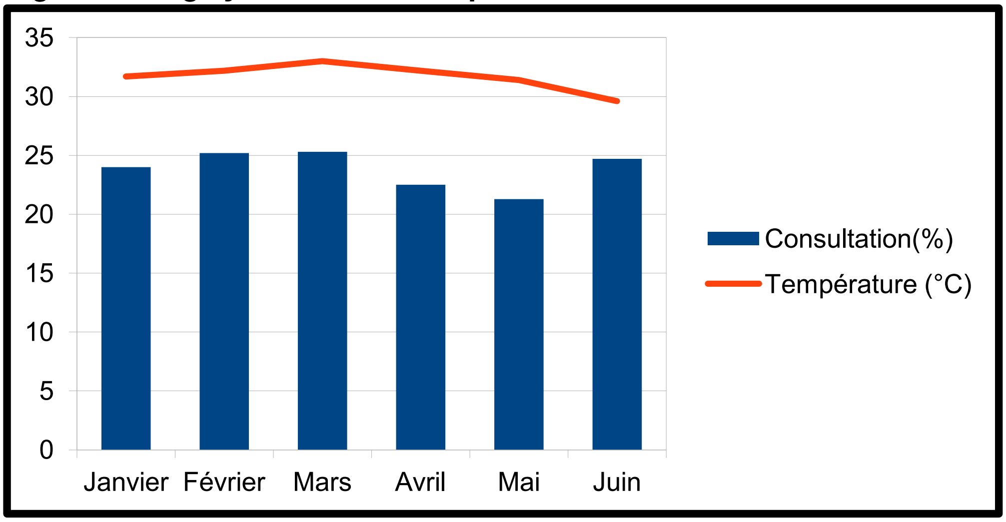
Source: Field survey, Abidjan, 2022

Surface temperature is a significant risk factor in analyses of morbidity rates in the surveyed population. Adults in the northern, western and central neighbourhoods, the most vulnerable to UHIs, reported health issues more frequently than those in the south, which are least exposed ($p<0.001$).

Increased exposure to surface temperatures leads to higher reporting of health problems, whereas lower exposure decreases the likelihood of seeking medical care.

The figure below shows that 26% of people who reported an illness used health services. Our interviews with older people, adults, and those who work outside indicate a desire to take personal charge of their health before seeking professional medical advice. People often wait until their illness becomes serious before going to health centres. Figure 11 highlights the limited accessibility of healthcare facilities, which may help explain the findings.

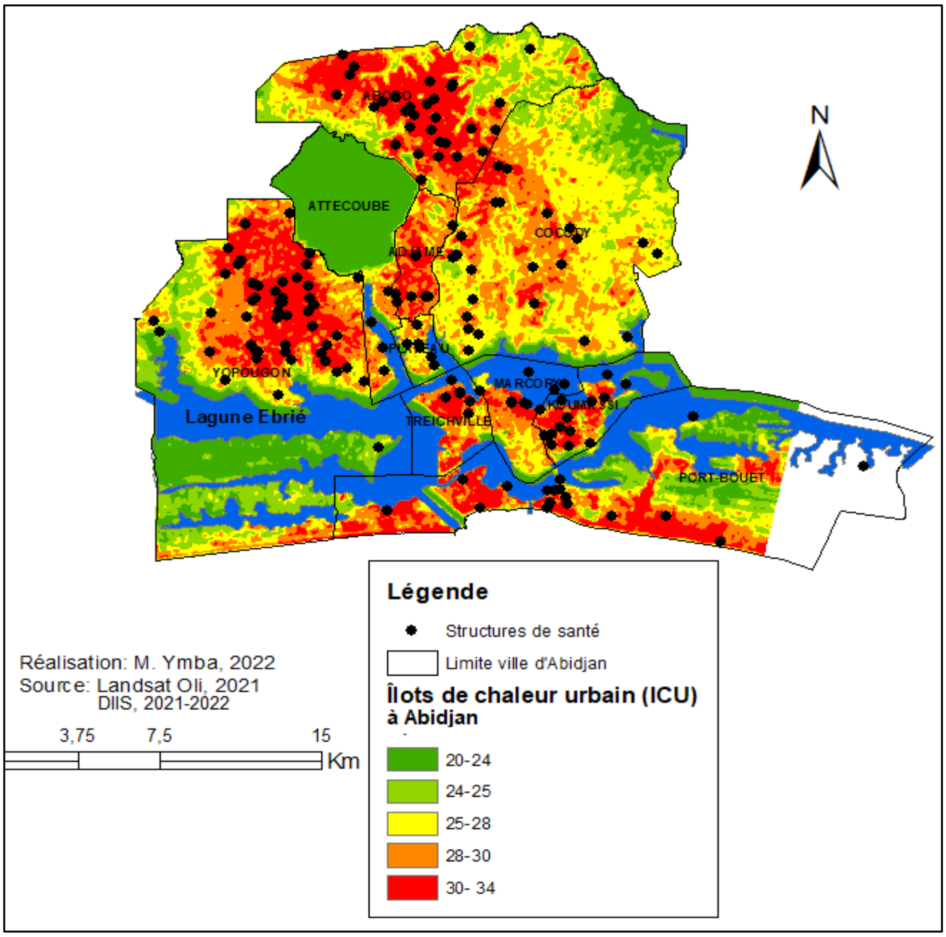
Figure 10. Highly uneven consumption of healthcare services



Source: Field survey, 2022

The distribution of healthcare facilities is very uneven, as shown in Figure 11. There are stark spatial disparities, particularly between east and west, and north and south. In areas with high surface temperatures, access to healthcare facilities is limited, resulting in poor care availability. Given the high number of declared pathologies, this makes the population extremely vulnerable.

Figure 11. Spatial distribution of healthcare facilities



Discussion

Based on spatial distribution, surface temperatures are found to be highest in densely built-up areas of the centre of Abidjan, the centre of Abobo, the southern area of Adjamé, the centre and south of Attécoubé, the centre of Yopougon, and the eastern and southern areas of Port-Bouët. These areas have a large human footprint and experience intense heat day and night. There is a decrease in temperature in vegetated areas of the conurbation. More vegetation tends to decrease the temperature. Areas with abundant vegetation tend to be coolest (A. Mobio et *al.*, 2017). The lack of vegetation in these areas due to densification and urbanisation makes them even more vulnerable. It is not uncommon for city centres to experience high temperatures. In 1833, Howard carried out one of the first urban climate studies. Based on daily readings, he discovered that temperatures in the heart of London were higher than in the surrounding areas with more vegetation. This phenomenon, the urban heat island (UHI) effect, refers to the temperature difference between highly urbanised areas and those with more vegetation, typically found in rural areas. The UHI effect occurs when the ground temperature in a city is 5 to 10°C higher than in surrounding areas (Camilloni et Barro, 1997; Charabi, 2001; Baudoin and Guay, 2005, p.1-8).

The multiple and varied urban surfaces and forms of town centres differ significantly from those of the countryside, where there is typically more vegetation and surface moisture. The urban heat island (UHI) is the thermal consequence of these differences. This is the temperature difference (ΔT) between the city centre and the surrounding countryside (Oke, 1987). Its spatial extension results from a combination of factors, including the city's geographical location, its shape (urban geometry), structure (division between mineral and plant surfaces) and size (surface area, density and population) Ringenbach (2004).

In cities, the roughness of urban surfaces contributes to the accumulation and intensification of heat due to the radiation-trapping effect in an "urban canyon", promoting the stagnation of warm air. A large amount of heat will be stored in urban buildings, subject to more substantial and slower thermal inertia compared to areas with more vegetation, as in Abidjan's densely urbanised central areas. At nightfall, hotter central urban surfaces, which have accumulated heat through radiation trapping, will take longer to cool due to decreased latent heat flux (Najjar et al., 2005).

The phenomenon of urban heat islands increases the frequency, duration, and intensity of extreme heatwaves, which can negatively impact the health and well-being of surveyed populations (Trottier, 2008). In most surveyed districts, respondents exposed to UHIs reacted badly to severe hot spells. At these times, perceived pain, such as severe migraines, extreme fatigue, heat stroke, overheating, dry cough, dizziness, fainting, and chest pain can cause fear. These clinical signs and symptoms are characteristic of the physiological state of patients who consult medical professionals during rising temperatures (WHO, 2017). Our findings have been confirmed by multiple studies carried out in Europe. These studies show extreme heat can cause discomfort and ailments (Giguère, 2009). Urban heat islands can cause weakness, loss of consciousness, cramps, blackouts and heat stroke. They can worsen pre-existing chronic illnesses such as diabetes, respiratory failure, and cardiovascular, cerebrovascular, neurological and renal diseases, to the point of causing death (Besancenot, 2002; Luber et McGeehin, 2008). The results of our research highlighted several climate-sensitive illnesses discussed in these studies that are more likely to affect vulnerable people, including malaria, digestive tract disorders, diabetes, respiratory tract disorders, skin infections, heart problems, and chronic pain. They were determined thanks to the precise and clear identification of clinical signs and symptoms. The high prevalence of these diseases led to a significant increase in the use of healthcare services despite their limited availability and accessibility.

According to climate forecasts, urban areas will experience severe heatwaves in the coming years. High temperatures and bright sunshine will contribute significantly to the formation of tropospheric ozone, a gas harmful to human health, in urban areas. Exposure to tropospheric ozone may cause eye and respiratory irritation, reduce lung function, worsen respiratory or heart diseases, and lead to premature death (WHO, 2007; Lamothe et al., 2019). In 2007, air pollution caused 1,540 premature deaths in Montreal, Canada (Guiguère, 2009).

Adaptation initiatives must be developed and sustained to protect public health and reduce vulnerability. The World Health Organisation (WHO) recommends health agencies and other stakeholders organise programmes to combat the effects of extreme heat and prevent the formation of urban heat islands to mitigate their adverse effects on health and well-being. In Côte d'Ivoire, as in many other African countries, the UHI phenomenon remains a little-known or studied phenomenon despite its harmful effects on health (E. J Legrand Soumy et *al.*, 2022). Action should be taken to reduce the harmful effects of UHIs on health and well-being, using successful strategies from other regions and adapting them to Côte d'Ivoire. Examining surface temperatures (Dousset et al., 2010) makes it feasible to monitor the UHI phenomenon using satellite images. Local media can then issue extreme heat warnings to vulnerable groups such as older people, children, and outdoor workers. Collecting solid data on UHIs can aid the implementation of specific emergency plans during extreme heat.

We also need to educate and train people on the UHI phenomenon and raise awareness of the health risks and precautions to take during extreme heat events. To combat UHIs, authorities must adopt energy-efficient building standards. Developers should be aware of the importance of preserving green spaces such as parks, gardens and vegetation. They should also encourage the spacing of dwellings and the use of high-albedo paving and roofing materials. Furthermore, planted roofs should be promoted, and subsidies should be offered to optimise the eco-energetic performance of buildings. This practice has been extensively tested in various urban areas in northern regions, yielding interesting results in mitigating UHIs (Guiguère, 2009).

Authorities must also address other environmental issues, such as proper management of household waste and improved wastewater sanitation affecting the neighbourhoods surveyed to effectively combat UHIs in Côte d'Ivoire (M. Ymba, 2016). Although not the focus of this paper, several other studies have highlighted an unhealthy environment on the ground. We have based our hypothesis on the fact that most of the illnesses listed by the population, such as malaria and diarrhoea, can result from the combination of several factors in an unhealthy environment.

Several environmental management factors have been overlooked in studies on UHIs. The challenges posed by the environmental management of hygiene issues have been primarily resolved in northern countries, where most studies have been conducted. We believe including this factor in Abidjan's UHI control plans is crucial. More detailed statistical analyses, such as logistic regression, are necessary to determine the contribution of each factor and identify the one with the most significant impact on population health. Taking these results into account would help improve the effectiveness of measures to mitigate UHIs. However, we believe that our results are relevant and raise awareness of UHIs and their impact on health. This study has also produced solid evidence to use as a starting point for action to help people affected by UHIs.

Conclusion

A surface temperature analysis revealed areas of concentrated heat in Abidjan, indicating the presence of urban heat islands. The central areas of the city, such as its core, are worst affected by the UHI phenomenon, along with the centre of Abobo, the southern area of Adjamé, the centre and southern areas of Attécoubé, the centre of Yopougon, and the eastern and southern areas of Port-Bouët. The heavy urbanisation of these areas makes them more susceptible to the formation of UHIs than outlying areas with abundant vegetation. This phenomenon can have adverse health effects. The superimposition of satellite images and data from epidemiological surveys has revealed the harmful effects of UHIs on older people, young children, and outdoor workers. During interviews, individuals reported various symptoms and clinical signs, including severe migraines, extreme fatigue, heat stroke, overheating, dry coughs, dizziness, fainting, and chest pains. These are typical physiological responses observed in patients during periods of high temperatures. The surveyed vulnerable populations reported various illnesses associated with these symptoms, including malaria, digestive tract disorders, diabetes, respiratory tract disorders, skin infections, heart problems, and chronic pain. The health impacts of UHIs are significant, especially on vulnerable populations. The high prevalence of these pathologies leads to a substantial increase in the use of healthcare services despite their limited availability.

Climate forecasts predict major heatwaves in urban areas in the coming years, although little is known about this phenomenon. The authorities in Côte d'Ivoire therefore need to take action to raise awareness among people about the health risks posed by UHIs and the measures to put in place to help protect them during periods of extreme heat in urban areas. This will mitigate the effects of UHIs on people's health.

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