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LAND ARTIFICIALIZATION AND INTENSIFICATION OF URBAN HEAT ISLANDS IN ABIDJAN, CÔTE D'IVOIRE: A SPATIOTEMPORAL ANALYSIS FROM 2002 TO 2024

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ABSTRACT

According to the Intergovernmental Panel on Climate Change (IPCC), changes in land cover could increase air temperature in urbanized areas by up to 4 °C by 2100. Urban heat islands are a major concern because of their effects on human health and economic activities. In Côte d'Ivoire, Abidjan is experiencing increasing frequency and intensity of heatwaves. However, the influence of spatiotemporal land use and land cover dynamics on UHI remains poorly documented. This study analyzes land use and land cover dynamics and their influence on UHI in Abidjan between 2002, 2014, and 2024. Landsat and MODIS AQUA data were used to map land cover and land surface temperature. The NDVI and NDBI indices were used to assess the influence of vegetation and built-up areas on UHIs. Relationships were analyzed using Pearson correlation and geographically weighted regression (GWR). Results show a 19.60 % increase in built-up areas and an 18.57 % decrease in vegetated areas. Mean UHI-related temperature increased from 30.22 °C to 31.88 °C, representing a rise of 1.66 °C. NDBI showed positive correlations with UHIs (0.65 in 2002, 0.74 in 2014, and 0.75 in 2024), while NDVI showed negative correlations (-0.63, -0.62, and -0.49, respectively). GWR results indicate spatial variations in these relationships, with predominantly positive NDBI coefficients and negative NDVI coefficients. These findings highlight the association between urbanization, vegetation loss, and UHI intensification in Abidjan, emphasizing the need to preserve vegetation and control urban expansion.

Keywords: Urban heat island, Land surface temperature, Urbanization, Land artificialization, Abidjan

1 INTRODUCTION

Urbanization represents the progress and modernization of cities and highlights the movement of inhabitants from rural areas to cities. Today, cities account for more than half of the total world population [1]. They have experienced rapid development in terms of physical infrastructure and technological progress over recent decades [2]. Urban areas continue to increase in terms of population and built-up extent, with faster rates in developing countries [3,4]. According to Nyamekye et al. [5], the benefits of urban growth in developing countries include employment opportunities, specialization, and improved production of goods and services. However, challenges include air pollution and water pollution in industrialized areas, while flash floods are frequent in highly impervious areas. Another notable challenge of urban development is rising temperatures, particularly in densely built-up areas [6]. Studies have shown that urban areas are comparatively warmer than undisturbed environments such as rural areas; this phenomenon is known as the urban heat island [7]. According to Gusso et al. [8], cities use construction materials such as concrete and asphalt, which do not allow water to penetrate and absorb a large amount of heat, thereby increasing urban temperatures. High temperatures can cause heat-related illnesses such as heat exhaustion, heatstroke, and skin cancer [9]. UHIs have maximized the number of heatwave days and tropical-like nighttime conditions in several major cities, including Paris, Baltimore, Washington DC, and Shanghai, during summer [10]. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) has highlighted that changes in land cover may increase air temperature in urbanized areas by 4°C by 2100 [11]. The associated changes and negative impacts seriously threaten the sustainable development of urban areas [12]. Urban land use, land cover heterogeneity, as well as changes in land cover classes (LCC), contribute to a complex and varied spatial pattern of heat intensities, which also vary from one city to another.

The city of Abidjan, the main economic hub of Côte d'Ivoire, is experiencing accelerated population growth. Its population increased from 4.7 million inhabitants in 2014 to 6.3 million inhabitants in 2021, representing an increase of approximately 4% per year [13]. This strong population growth is accompanied by significant urbanization, with a rate estimated at nearly 49% in 2020 [14]. Furthermore, over the past 10 years, the city of Abidjan has experienced an increase in the frequency (increased number of days of oppressive heat) and magnitude (intensity and duration) of heatwaves [15]. This continuous increase in observed temperature, together with the high rate of urbanization, could intensify the UHI phenomenon in the city of Abidjan. The present study aims to analyze the spatiotemporal dynamics of land cover, as well as its influence on the spatial distribution of urban heat islands in Abidjan between 2002, 2014, and 2024.

2 MATERIALS AND METHODS

2.1 Study area

The city of Abidjan is located in the south of Côte d'Ivoire between latitude 5°15N and 5°26N and longitude 4°5W and 3°54W (Figure 1).

It is the largest and most populated city in the country (accounting for 20% of the national population) [13] and in Francophone West Africa. It covers an area of 422 km² with an estimated population density of about 15,050 inhabitants/km² and comprises more than 280 neighborhoods. Abidjan is divided into two main areas: "North Abidjan," composed of the communes of Plateau, Adjamé, Attécoubé, Cocody, Yopougon, and Abobo, and "South Abidjan," consisting of the communes of Treichville, Marcory, Koumassi, and Port-Bouët. The two areas are separated by the Ébrié Lagoon. The Abidjan region is located within a climatic zone covering low Côte d'Ivoire below the 8th parallel. It is influenced by a sub-equatorial climate. Four seasonal patterns are distinguished (two dry seasons and two rainy seasons) [16].

2.2 Data

Landsat satellite images were used to map the land cover dynamics of Abidjan at three different dates: one Landsat 7 image from 2002 (30 m spatial resolution) and two Landsat 8 images with a 30 m spatial resolution, acquired in 2014 and 2024, respectively. The processing and analysis of these data were carried out using the Google Earth Engine (GEE) platform, a high-performance cloud environment that provides direct access, efficient manipulation, and rapid processing of satellite images without the need for local downloading [17]. The choice of Landsat 7 and Landsat 8 images, with a homogeneous spatial resolution of 30 m, ensures data consistency and allows reliable comparability of land cover classes over time. This study period also corresponds to major phases of population growth and urban expansion in Abidjan.

MODIS LST data with a 1 km resolution were acquired from the 8-day composite land surface temperature (LST) product (MYD11A2) of the MODIS Aqua platform. The MODIS product (MYD11A2) provides an average of daytime LST

over 8 days. MODIS products are mainly used for global and regional studies because of their coarse spatial resolution [18], which is suitable for estimating LST over a large city such as Abidjan.

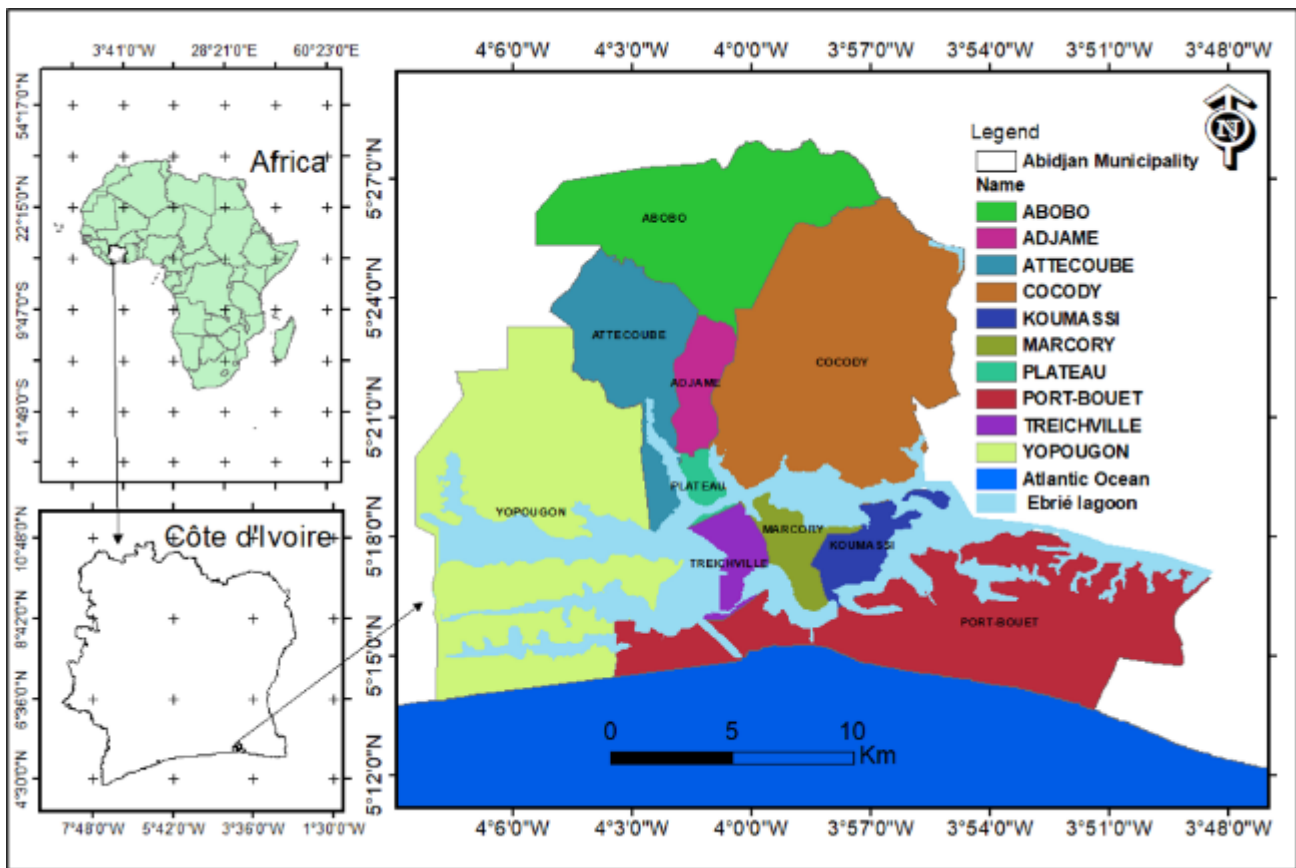


Figure 1: Location of the study area

The MODIS land product, specifically the 500 m resolution land surface reflectance product (MYD09GA), was used to determine the Normalized Difference Vegetation Index (NDVI), which indicates green areas, and the Normalized Difference Built-up Index (NDBI), which represents built-up land.

2.3 Methods

- Land cover mapping of Abidjan
- Using the Google Earth Engine (GEE) platform, a Landsat Collection 2 image dataset was used. Based on knowledge of the study area, four land cover classes were defined: built-up areas, bare soil, water bodies, and vegetation.
- The process used to develop the land cover maps for 2002, 2014, and 2024 is described as follows [19]:
- the boundary of Abidjan was imported as a Shapefile (study area) and stored in the user account as a variable,
- the image dataset (USGS Landsat Collection 2 Level 2 TOA reflectance) was defined as a variable,
- four new feature collections were created using the drawing tools of the code editor. Each collection contains polygons representing pixels associated with one of the land cover classes,
- after defining the satellite sensor, the image dataset was filtered by clipping the data within the boundaries of the study area. It was then filtered according to the percentage of cloud cover and the image acquisition date. Specific bands were subsequently used for visualization and analysis,
- all feature collections were merged into a single feature that contains all the values of the land cover classes,
- the application of a classifier (random forest) makes it possible to classify the image data into four classes based on the previously determined training samples, and then to identify a range of colors for visualizing the results.

2.4 Estimation of land surface temperature

Daytime LST data were extracted from the MODIS MYD11A2 product, specifically from the LST_Day_1km layer. Equation 2 from Noi et al. [20] was used to convert these temperature values into degrees Celsius:

$$C = LST_{Day} \times 0,02 - 273,15 \quad (1)$$

Where :

- C is the temperature in degrees Celsius,
- LST_Day_1km is the land surface temperature in Kelvin, as extracted from the MODIS MYD11A2 product,
- The factor 0.02 is applied to convert Kelvin to degrees,
- The constant -273.15 is used to convert Kelvin to Celsius, as absolute zero (0 Kelvin) corresponds to -273.15°C.

2.5 Relationship between land cover and urban heat islands

2.5.1 Spatial association of ICU

This study aims to apply spatial association statistics, specifically the Global Moran's Index (Moran's I), to examine the existence of a correlation between the observed values at a given spatial location and those of neighboring locations. The Global Moran's Index ranges from -1 to 1. A positive value of the Global Moran's Index indicates positive spatial autocorrelation, meaning that the higher the index value, the stronger the spatial association. A negative value indicates negative spatial autocorrelation. In contrast, a Moran's I value = 0 indicates the absence of spatial autocorrelation, meaning that the variable under study, particularly the UHI, is randomly distributed in space [20]. The following formula is used to calculate the Global Moran's Index [21].

$$I = \frac{n \sum \omega_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\omega \sum (x_i - \bar{x})^2} \quad (2)$$

Where n is the number of points; x_i and x_j are the UHI values of samples i and j , respectively; ω_{ij} is the spatial weight describing the distance between i and j ; and $\bar{x}$ is the mean UHI value. However, the Global Moran's I index does not show the geographical location of high and low UHI values within the study area. To this end, local indicators of spatial association, namely High-High (HH) clusters, Low-Low (LL) clusters, High-Low (HL) clusters, and Low-High (LH) clusters, were used to explore the geographical location of such clustered/dispersed UHI patterns. HH clusters indicate relatively high values of clustered spatial units, whereas LL clusters indicate relatively low values of clustered spatial units. HL outliers indicate high and low values of clustered spatial units [21].

2.5.2 Ordinary least squares and geographically weighted regression models

Spectral indices, particularly the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI), were used to assess the influence of vegetation and built-up surfaces on UHIs. The relationships between these variables were analyzed using ordinary least squares (OLS) and geographically weighted regression (GWR) models in order to account for their spatial variability. According to Yang et al. [22], non-spatial models such as OLS are unable to adequately capture spatial relationships. Consequently, an additional GWR analysis was necessary. According to Selon Ansein & Rey, [23], OLS can be expressed as follows:

$$y_i = \beta_0 + \sum_{j=1}^k \beta_j x_{ij} + \varepsilon_i \quad (5)$$

Where Y_i is the observation of the dependent variable, X_i is the observation of the independent variable, β is a regression coefficient of the variable, and ε_i is the error term. Mathematically, the GWR model can be expressed as demonstrated by Anselin et al. [24].

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^n \beta_k(u_i, v_i) x_{ik} + \varepsilon_i \quad (6)$$

Where (u_i, v_i) is the geographic coordinate of the location; β_0 is a constant term; $\beta_k(u_i, v_i)$ is the regression coefficient of each variable at point i ; and ε_i is the random error term at point i .

3 RESULTS

3.1 Evolution of land cover in the city of Abidjan between 2002 and 2024

The detailed analysis of Figures 2 and 3 on land cover changes in Abidjan between 2002 and 2024 highlights significant trends in urbanization, land use, and changes in urban landscapes. In 2002, the city of Abidjan showed urbanization concentrated mainly in central districts such as Adjamé, Marcory, Koumassi, and Treichville, which were almost entirely covered by built-up areas. In contrast, peripheral districts such as Yopougon, Abobo, Cocody, and Port-Bouët were still partially urbanized, with bare soil areas visible around built-up areas. Between 2002 and 2014, a significant transition occurred, with rapid expansion of built-up areas in peripheral districts such as Yopougon, Abobo, Cocody, and Port-Bouët. This process resulted in a loss of vegetation cover and bare soil, promoting rapid urbanization at the expense of

natural areas. Port-Bouët particularly illustrates this dynamic, where the bare soil areas of 2002 were progressively replaced by dense built-up areas in 2014.

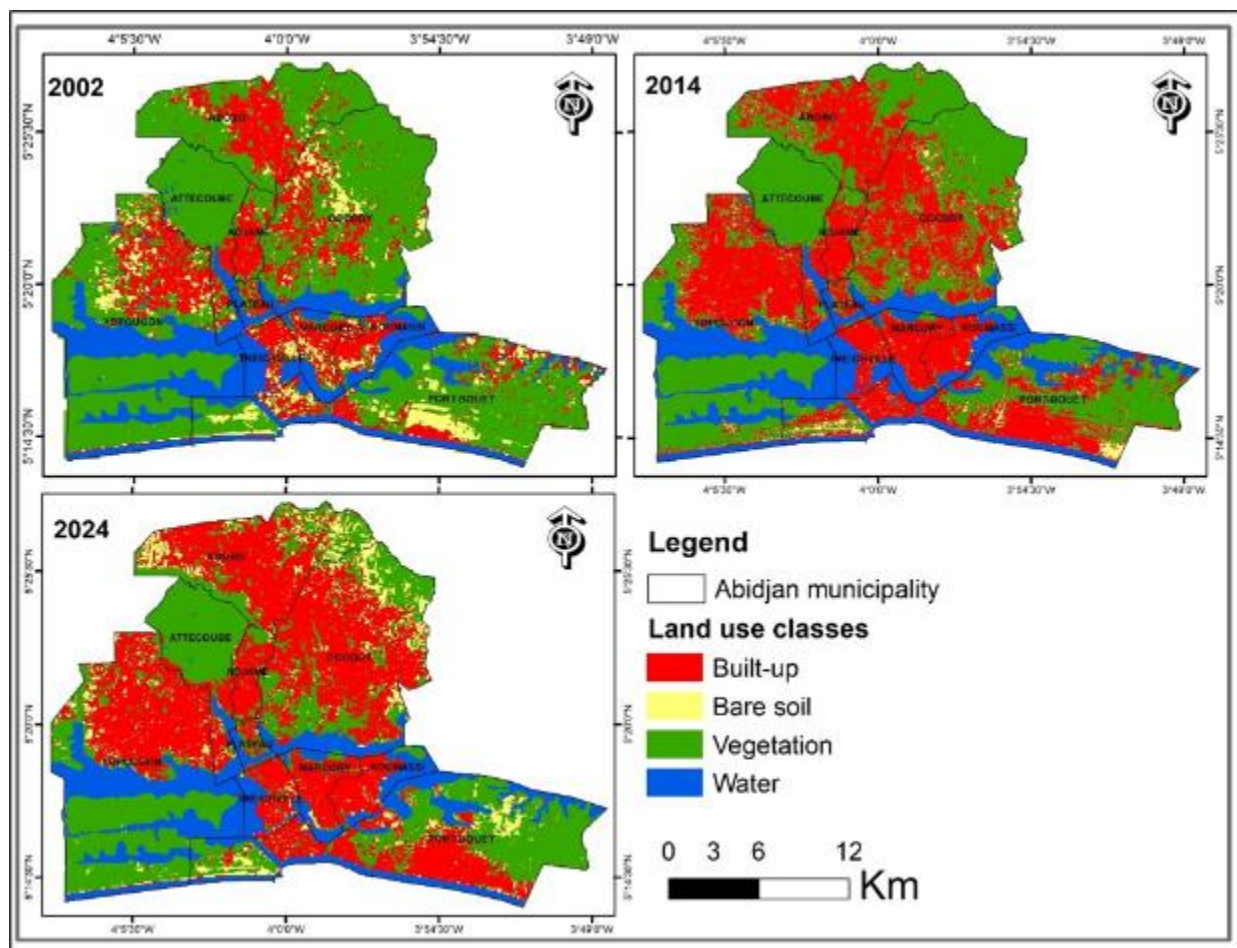


Figure 2: Land cover map of the city of Abidjan in 2002, 2014, and 2024

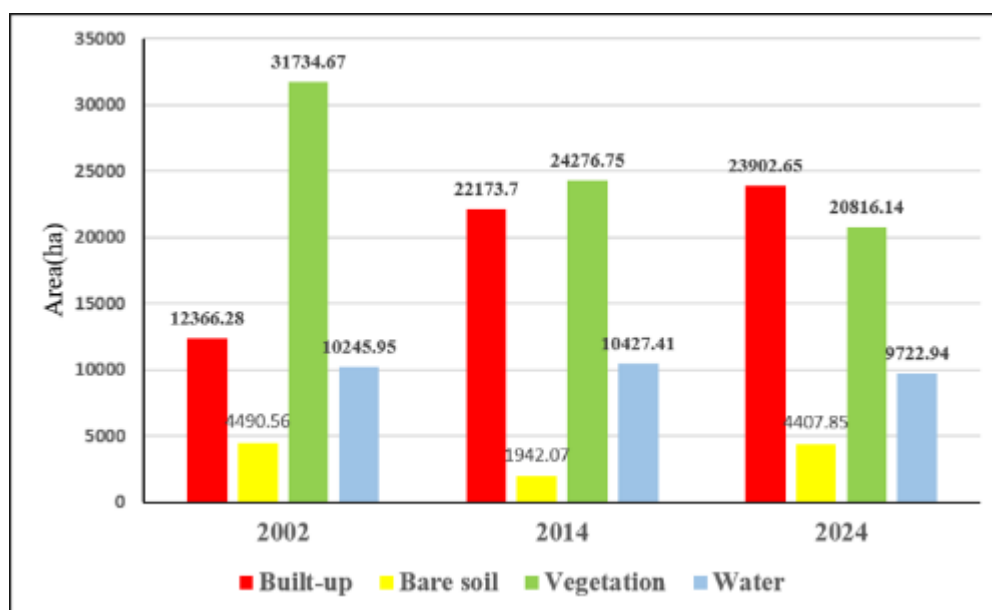


Figure 3: Evolution of land cover classes (2002, 2014, and 2024)

In 2024, built-up areas represented 40.62 % of the total area of the city of Abidjan, corresponding to nearly 23,903 ha, marking a spectacular increase compared with 2002, when they covered only 21.02 % (approximately 12,366 ha). This exponential growth in built-up areas reflects the rapid urbanization of the city. In 2002, the area covered by vegetation

was approximately 31,734 ha, representing a significant proportion of the territory. However, in 2024, this area had decreased to 20,816 ha, representing a decline of 18.57 %. Bare soil areas, which accounted for approximately 7.63 % of the territory of Abidjan in 2002, experienced a significant decrease until 2014, when they represented only 3.30 % of the territory. However, between 2014 and 2024, the proportion of bare soil increased again, reaching 7.49 % in 2024. This trend reflects the transformation of certain built-up areas, where developed areas were converted into vacant or undeveloped land. For example, northern Port-Bouët shows built-up areas in 2014 that were reclassified as bare areas in 2024.

3.2 Spatiotemporal distribution of urban heat islands in Abidjan

Figure 4 presents the spatial distribution of UHI in the city of Abidjan for the years 2002, 2014, and 2024. In 2002, the maximum UHI value reached 37 °C, while the minimum value was 25.38 °C. In 2014, the maximum and minimum recorded values were 37.86 °C and 24.94 °C, respectively. In 2024, the maximum UHI value decreased slightly to 36.36 °C, while the minimum UHI value increased from 24.94 °C in 2014 to 27.52 °C in 2024. The intensity of UHI decreases from the city center toward the outskirts. Hotspots, where UHI values are highest, are mainly concentrated in highly urbanized districts such as Koumassi, Treichville, and Marcory, the north-central part of Yopougon, the central-western part of Abobo, as well as areas such as Port-Bouët, Adjamé, Cocody, Attécoubé, and northern Plateau. These areas correspond to sectors with high urban density and recent or intensified development, often characterized by a large number of buildings, roads, and limited green spaces.

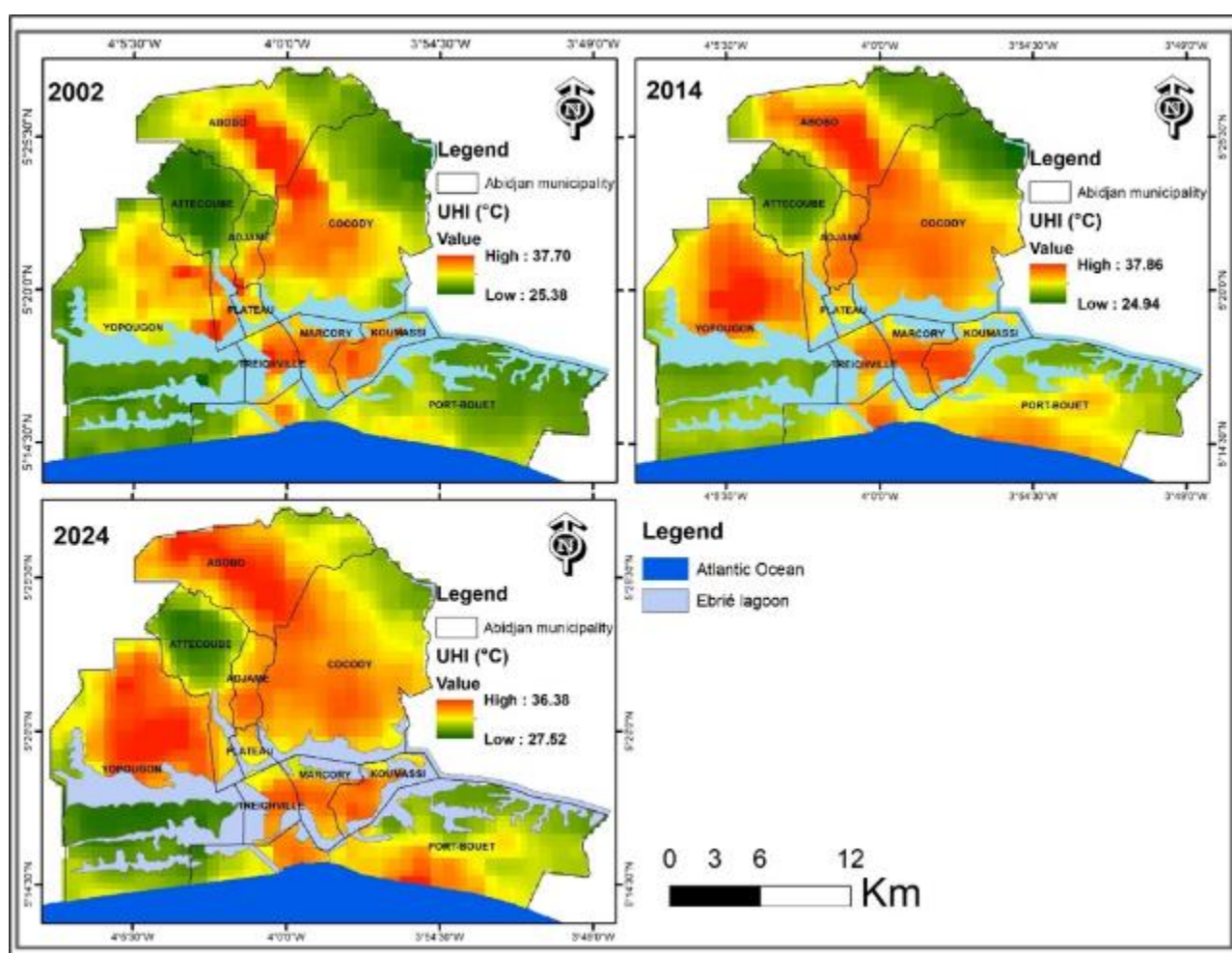


Figure 4: Spatiotemporal distribution of urban heat islands in Abidjan in 2002, 2014, and 2024

3.3 Relationship between land cover and urban heat islands

3.3.1 Spatial association of urban heat islands

The Global Moran's Index remains close to 1 for the three years considered (0.90, 0.92, and 0.92 in 2002, 2014, and 2024, respectively). This indicates a strong positive spatial autocorrelation of UHIs in the study area. High UHI levels tend to be close to areas with high urban temperatures, and conversely, areas with low UHI levels tend to be close to areas with low UHI levels. Figure 5 presents the results of the local indicators of spatial association.

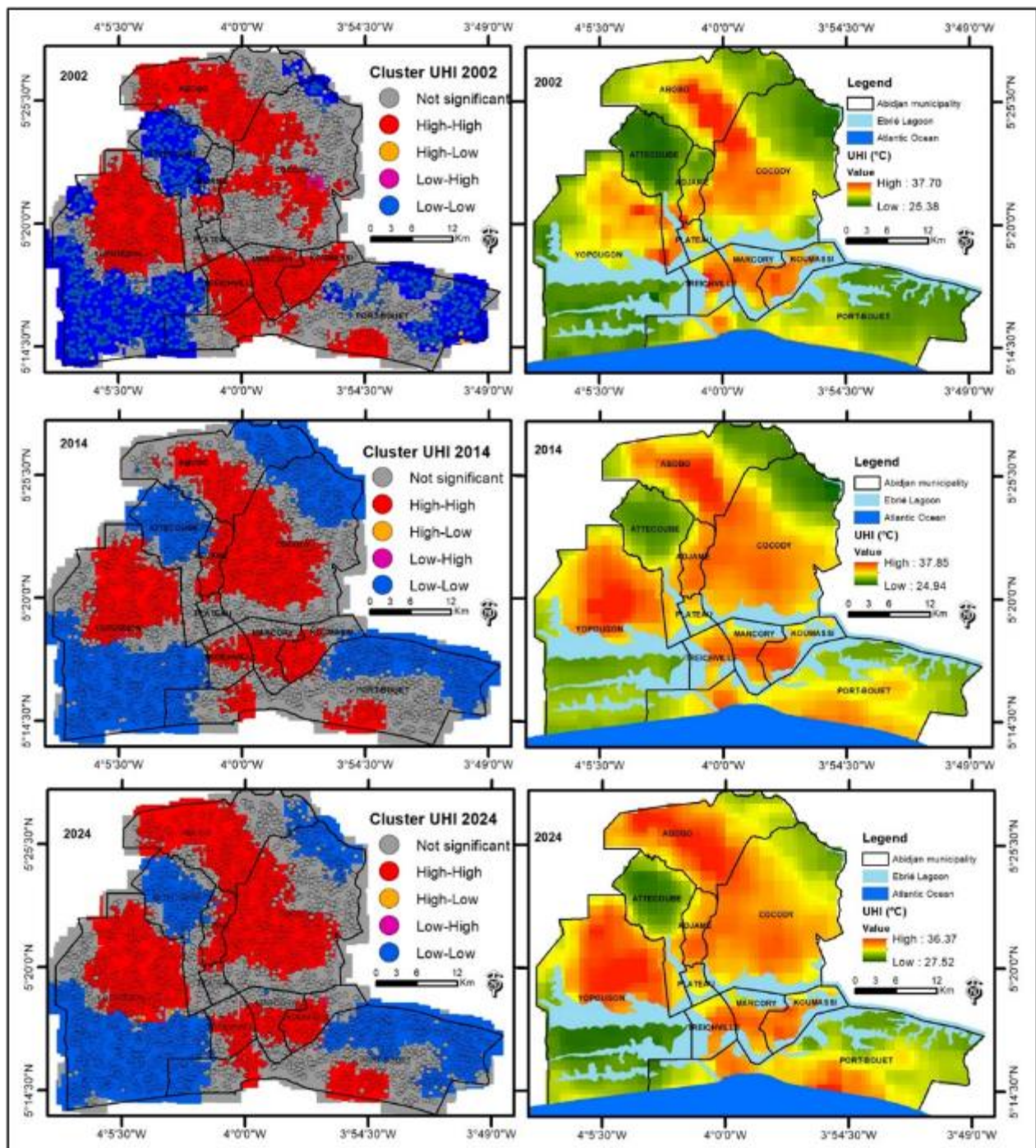


Figure 5: Indicateurs locaux d'associations spatiales (ILAS) et répartition spatiale d'ICU

It shows that UHI values represented by High-High (HH) clusters are located in highly urbanized areas (central-western Abobo, central-southern Yopougon, the entire area of Treichville, Marcory, and Koumassi). In addition, the area of HH zones increases over time, from 497.27 ha in 2002 to 532.1107 ha in 2014 and 638.60 ha in 2024. Low-Low (LL) clusters, indicating the lowest UHI values, are located in highly vegetated areas. These areas include northern Attécoubé, southern Yopougon, and eastern Port-Bouët. Unlike the area of HH zones, the area of LL zones decreases progressively. Indeed, it decreased from 660.56 ha in 2002 to 576.66 ha in 2014 and 532.1107 ha in 2024.

3.4 Analysis of Pearson correlation and geographically weighted regression results

The results show a consistent relationship between land cover characteristics and UHI in Abidjan. Pearson's correlation analysis highlights a negative relationship between NDVI and UHI for the three years studied. The coefficients are -0.63 in 2002, -0.62 in 2014, and -0.49 in 2024 (Table I). These values indicate a relatively strong inverse relationship between vegetation and UHI, although the strength of this relationship decreased in 2024. Areas with greater vegetation cover are associated with lower urban temperatures. The decrease in the correlation coefficient between NDVI and UHI, from -0.63 in 2002 to -0.49 in 2024, suggests that the relationship between vegetation cover and temperature became less

pronounced over the study period. Conversely, NDBI shows a positive correlation with UHI for all the years studied. The coefficients increased from 0.65 in 2002 to 0.74 in 2014 and 0.75 in 2024. This increase indicates an increasingly pronounced relationship between built-up surfaces and temperatures. Areas characterized by a high presence of buildings are more strongly associated with high UHI values. The increase in the coefficient between 2002 and 2024 is consistent with the spatial expansion of built-up areas during this period.

The results of the geographically weighted regression confirm this spatial variability. The local NDBI coefficients show substantial variations across the sectors of the study area. They range from -23.30 to 54.02 in 2002, from -7.82 to 41.62 in 2014, and from -1.83 to 41.62 in 2024. The majority of the coefficients are positive, confirming that an increase in built-up surfaces is generally associated with an increase in UHI. High positive coefficients indicate a strong relationship between built-up intensification and urban temperatures in certain sectors. However, the presence of low or negative NDBI coefficients in some sectors shows that this relationship is not uniform across Abidjan. Regarding NDVI, the local GWR coefficients range mainly from -15.95 to 2.01 in 2002, from -19.39 to 4.55 in 2014, and from -21.57 to 9.35 in 2024. The majority of the coefficients are negative for all three years. This distribution confirms that vegetation has an inverse effect on UHI. Areas with greater vegetation tend to have lower UHI values. The most strongly negative coefficients indicate a stronger association between the presence of vegetation and the reduction of urban temperatures. However, some areas show positive NDVI coefficients, particularly in southern Cocody, Yopougon, and eastern Port-Bouët between 2002 and 2014. These positive values show that the effect of vegetation on UHI is not spatially homogeneous. They may reflect local situations in which the relationship between vegetation and temperature is influenced by other characteristics of the urban environment.

Overall, the Pearson and GWR results converge toward the same trend. NDBI is positively associated with UHI, whereas NDVI is negatively associated with them. The positive relationship with NDBI becomes stronger over the 2002-2024 period, while the negative relationship with NDVI weakens in 2024. At the same time, GWR shows that these relationships vary spatially across Abidjan. UHI therefore result from the interaction between vegetation, built-up intensity, and the characteristics specific to different urban sectors.

Table 1: Pearson correlation matrix (at p-value < 0.001)

	UHI_20 02	UHI_20 14	UHI_20 24	NDBI_20 02	NDBI_20 14	NDBI_20 24	NDVI_20 02	NDVI_20 14	NDVI_20 24
UHI_2002	1.00								
UHI_2014	0.82	1.00							
UHI_2024	0.80	0.91	1.00						
NDBI_2002	0.65	0.74	0.64	1.00					
NDBI_2014	0.66	0.74	0.74	0.70	1.00				
NDBI_2024	0.63	0.68	0.75	0.65	0.77	1.00			
NDVI_2002	-0.63	-0.56	-0.51	-0.70	-0.50	-0.53	1.00		
NDVI_2014	-0.65	-0.62	-0.56	-0.64	-0.54	-0.57	0.88	1.00	
NDVI_2024	-0.52	-0.47	-0.49	-0.60	-0.50	-0.61	0.74	0.75	1.00

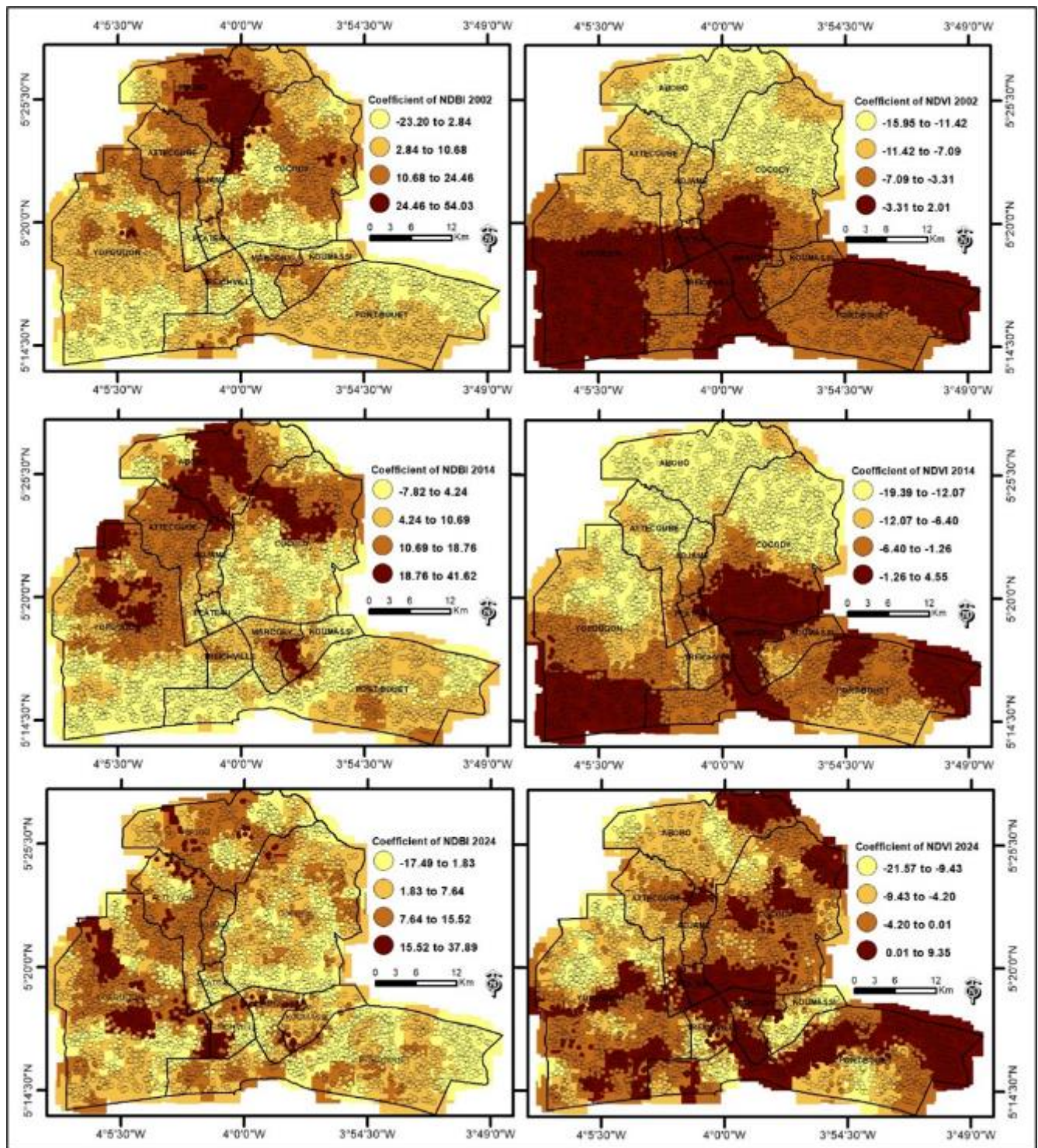


Figure 6: Spatial distribution of local coefficients for NDBI and NDVI in 2002, 2014, and 2024

4 DISCUSSION

The analysis of the results of the land cover maps indicates an increase of approximately 19.6% in built-up areas and a reduction in vegetated areas (-18.57 %) between 2002 and 2024. This change reflects the rapid urbanization of the city of Abidjan associated with population growth, which may have been driven by the decade (2002-2011) of civil unrest that led to a massive influx of population into Abidjan, as observed by Yao et al. [25]. Moreover, as the economic capital of Côte d'Ivoire, Abidjan attracts a large population from rural areas and neighboring countries, resulting in increased demand for housing. In response to this pressure, vegetated areas are progressively converted into residential, commercial, or infrastructural areas to meet housing and economic activity needs. Furthermore, between 2014 and 2024, the area of bare soil increased from 3.30% to 7.49%, representing an increase of 4.19%. This increase in bare soil could be explained by the eviction and relocation operations (removal of populations encroaching on public spaces or

populations occupying risk-prone areas) carried out by the Ivorian Government to improve sanitation in the city of Abidjan. Several built-up areas were demolished, giving way to spaces that are now classified as bare soil.

Mean UHI were higher in built-up and bare areas than in vegetated areas. Hotspots, where UHI values are the highest, are mainly concentrated in highly urbanized neighborhoods such as Koumassi, Treichville, and Marcory, the north-central part of Yopougon, the central-western part of Abobo, as well as areas such as Port-Bouët, Adjamé, Cocody, Attécoubé, and northern Plateau. These results are consistent with those of Mobio et al. [26] et Ymba, [27]. Indeed, Effat Effat & Hassan [28] note that buildings, roads, and other impervious surfaces that make up built-up areas increase the absorption of solar radiation as well as the thermal capacity and thermal conductivity of these areas. According to Nkechi et al. [29] and Shah & Ghauri [30], buildings reduce heat removal by advection and reduce the sky view factor, thereby limiting heat dissipation toward space, while walls and pavements absorb and emit heat. This is confirmed by the correlation analysis between UHI and land cover indices. Indeed, the significantly positive correlation between UHI and NDBI supports the conclusions of these authors. This positive correlation indicates that as built-up areas increase, UHIs also increase. These results are consistent with those of Demisse Negesse et al. [31], who showed that there was a strong positive correlation between built-up areas and UHI.

The low UHI values in vegetated areas result from the buffering effect of vegetation through shading and the evapotranspiration process [32]. There is a negative correlation between UHI and NDVI. An increase in vegetated areas will therefore lead to a decrease in UHI [33]. Demisse et al. [34] showed in Addis Ababa, Ethiopia, that trees and other plants contribute to cooling the environment, making green spaces a simple and effective means of mitigating the effects of UHI. According to Li et al. [35], urban development does not necessarily have to create an undesirable impact on the local climate if it is properly managed. Rapidly growing cities should therefore ensure that their development dynamics are oriented toward mitigating potentially harmful environmental impacts through the creation of vegetated areas.

5 CONCLUSION

This study highlights the determining role of land cover transformations and population growth in the intensification of urban heat islands in Abidjan. Between 2002 and 2024, built-up areas increased from 21.02% to 40.62% of the study area, representing an increase of 19.60 percentage points, while vegetated areas decreased by 18.57 percentage points. This change was accompanied by an increase in the mean temperature associated with UHI, from 30.22 °C in 2002 to 31.88 °C in 2024, representing an increase of 1.66 °C over 22 years.

The spatial analysis further confirms the structured nature of this thermal dynamic. The high values of the Global Moran's Index indicate strong positive spatial autocorrelation of UHI, reflecting the spatial clustering of sectors with similar thermal levels. Pearson correlation analyses also highlight a positive relationship between built-up surfaces and UHI, with NDBI coefficients of 0.65 in 2002, 0.74 in 2014, and 0.75 in 2024. Conversely, NDVI shows a negative relationship with UHIs, with coefficients of -0.63, -0.62, and -0.49 in 2002, 2014, and 2024, respectively. These results therefore show that the increase in artificialized surfaces is associated with an intensification of urban temperatures, whereas the presence of vegetation contributes to their mitigation.

The geographically weighted regression further confirms that the influence of built-up areas and vegetation on UHI varies across the different sectors of Abidjan. The coefficients associated with NDBI are predominantly positive, with values ranging from -23.30 to 54.02 in 2002, from -7.82 to 41.62 in 2014, and from -1.83 to 41.62 in 2024. Conversely, the NDVI coefficients are predominantly negative, ranging from -15.95 to 2.01 in 2002, from -19.39 to 4.55 in 2014, and from -21.57 to 9.35 in 2024. This spatial variability highlights that the effects of urbanization and vegetation cover are not homogeneous across the city.

In this context, urban vegetation appears to be an important lever for mitigating UHI, particularly through shading, evapotranspiration, and regulation of the urban microclimate. These results therefore highlight the need to further integrate thermal issues into urban planning policies through the preservation and enhancement of vegetated areas, the limitation of artificialization and unplanned urban sprawl, as well as the promotion of urban forms that favor natural ventilation. Better consideration of these dimensions in urban planning could contribute to limiting the intensification of UHI and sustainably improving thermal conditions across the different sectors of the city.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

REFERENCES

- [1] Angel S, Parent J, Civco DL, Blei A, Potere D. The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Progress in Planning*. 1 févr 2011;The dimensions of global urban expansion: Estimates and projections for all countries, 2000–205075(2):53-107. doi:10.1016/j.progress.2011.04.001
- [2] Güneralp B, Reba M, Hales BU, Wentz EA, Seto KC. Trends in urban land expansion, density, and land transitions from 1970 to 2010: a global synthesis. *Environ Res Lett*. 20 mars 2020;15(4):044015. doi:10.1088/1748-9326/ab6669
- [3] Ahmed B, Ahmed R. Modeling urban land cover growth dynamics using multi-temporal satellite images: a case study of Dhaka, Bangladesh. *ISPRS International Journal of Geo-Information*. 2012;1(1):3-31.
- [4] Nyamekye C, Kwofie S, Ghansah B, Agyapong E, Boamah LA. Assessing urban growth in Ghana using machine learning and intensity analysis: A case study of the New Juaben Municipality. *Land Use Policy*. 1 déc 2020;99:105057. doi:10.1016/j.landusepol.2020.105057
- [5] Shi T, Huang Y, Wang H, Shi CE, Yang YJ. Influence of urbanization on the thermal environment of meteorological station: Satellite-observed evidence. *Advances in Climate Change Research*. 1 mars 2015;6(1):7-15. doi:10.1016/j.accre.2015.07.001
- [6] Behrendt A, Wagner G, Petrova A, Shiler M, Pal S, Schaberl T, et al. Modular lidar systems for high-resolution 4-dimensional measurements of water vapor, temperature, and aerosols. In: *Lidar Remote Sensing for Industry and Environmental Monitoring V* [Internet]. SPIE; 2005 [cité 18 déc 2025]. p. 220-7.
- [7] Gusso A, Bordin F, Veronez M, Cafruni C, Lenz L, Crija S. Multitemporal Analysis of Thermal Distribution Characteristics for Urban Heat Islands Management. In: *Proceedings of The 4th World Sustainability Forum* [Internet]. Sciforum.net: MDPI; 2014 [cité 7 janv 2025].
- [8] Orimoloye IR, Mazinyo SP, Nel W, Kalumba AM. Spatiotemporal monitoring of land surface temperature and estimated radiation using remote sensing: human health implications for East London, South Africa. *Environ Earth Sci*. 24 janv 2018;77(3):77. doi:10.1007/s12665-018-7252-6
- [9] Naghibi F, Delavar MR, Pijanowski B. Urban growth modeling using cellular automata with multi-temporal remote sensing images calibrated by the artificial bee colony optimization algorithm. *Sensors*. 2016;16(12):2122.
- [10] GIEC. *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Internet]. 1^{re} éd. Cambridge University Press; 2023.
- [11] Ishola KA, Okogbue EC, Adeyeri OE. A Quantitative Assessment of Surface Urban Heat Islands Using Satellite Multitemporal Data over Abeokuta, Nigeria. *International Journal of Atmospheric Sciences*. 3 mai 2016;2016:6. doi:10.1155/2016/3170789
- [12] RGPH. Recensement Général de la Population et de l'Habitat 2021 [Internet]. 2021 [cité 26 juill 2024]. p. 37.
- [13] OECD. *Dynamiques de l'urbanisation africaine 2020: Africapolis, une nouvelle géographie urbaine* [Internet]. Paris: Organisation for Economic Co-operation and Development; 2020 [cité 5 avr 2023].
- [14] SODEXAM. Déclaration du Directeur de la SODEXAM sur l'état du climat en Afrique et la Côte d'Ivoire. 2015. p. 32.
- [15] Kouassi AM, Nassa RK, Ahoussi KE, Kouame KF, Biemi J. Evolution des normales des pluies extrêmes en Afrique de l'ouest: cas du district d'Abidjan (sud de la cote d'ivoire). *Agronomie Africaine*. 2021;33(2):243-52.
- [16] Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*. 1 déc 2017;Big Remotely Sensed Data: tools, applications and experiences202:18-27. doi:10.1016/j.rse.2017.06.031
- [17] Akinyemi FO, Ikanyeng M, Muro J. Land cover change effects on land surface temperature trends in an African urbanizing dryland region. *City and Environment Interactions*. déc 2019;4:10. doi:10.1016/j.cacint.2020.100029
- [18] Hasan SH, AL-Hameedawi ANM, Ismael HS. Supervised Classification Model Using Google Earth Engine Development Environment for Wasit Governorate. *IOP Conf Ser: Earth Environ Sci*. 1 janv 2022;961(1):012051. doi:10.1088/1755-1315/961/1/012051

- [19] Noi P, Degener J, Kappas M. Comparison of Multiple Linear Regression, Cubist Regression, and Random Forest Algorithms to Estimate Daily Air Surface Temperature from Dynamic Combinations of MODIS LST Data. *Remote Sensing*. 25 avr 2017;9(5):398. doi:10.3390/rs9050398
- [20] Kumari M, Sarma K, Sharma R. Using Moran's I and GIS to study the spatial pattern of land surface temperature in relation to land use/cover around a thermal power plant in Singrauli district, Madhya Pradesh, India. *Remote Sensing Applications: Society and Environment*. 1 août 2019;15:100239. doi:10.1016/j.rsase.2019.100239
- [21] Guo A, Yang J, Sun W, Xiao X, Xia Cecilia J, Jin C, et al. Impact of urban morphology and landscape characteristics on spatiotemporal heterogeneity of land surface temperature. *Sustainable Cities and Society*. 1 déc 2020;63:102443. doi:10.1016/j.scs.2020.102443
- [22] Yang L, Yu K, Ai J, Liu Y, Yang W, Liu J. Dominant Factors and Spatial Heterogeneity of Land Surface Temperatures in Urban Areas: A Case Study in Fuzhou, China. *Remote Sensing*. janv 2022;14(5):5. doi:10.3390/rs14051266
- [23] Anselin L, Rey S. Properties of Tests for Spatial Dependence in Linear Regression Models. *Geographical Analysis*. 1991;23(2):112-31. doi:10.1111/j.1538-4632.1991.tb00228.x
- [24] Anselin L, Li X, Koschinsky J. GeoDa, From the Desktop to an Ecosystem for Exploring Spatial Data. *Geographical Analysis*. 2022;54(3):439-66. doi:10.1111/gean.12311
- [25] Yao K, Idrees MO, Pradhan B, Nabeel SM. Detecting Land Use Land Cover Change Impacted by Civil Crisis in Ivory Coast using Remote Sensing and GIS. Vol. 03. 2015;03.
- [26] Mobio BH, Fourier D, Damien KAK, Valère DME, Kouadio A. Contribution De La Télédétection A L'étude De La Distribution Spatiale De La Température En Fonction Du Relief Et Du Mode D'occupation Du Sol : Cas De La Ville d'Abidjan (Côte d'Ivoire). *International Journal of Engineering Science Invention*. 2017;6(12):48-55.
- [27] Ymba M. Analyse des effets des îlots de chaleur urbains sur la santé des populations de la ville d'Abidjan (Côte d'Ivoire). *Les Papiers de la Fondation*. 2022;Fondation Croix-Rouge française,(46):24.
- [28] Effat HA, Hassan OAK. Change detection of urban heat islands and some related parameters using multi-temporal Landsat images; a case study for Cairo city, Egypt. *Urban Climate*. 2014;10:171-88.
- [29] Nkechi BC, Babatunde A, Dera BP, Daniel O. Impact Assessment of Urban Heat Island on Land Use/Land Cover in Owerri Metropolis Using Geospatial Technique. *International Journal of Advances in Engineering and Management*. 2024;6(9):462-73.
- [30] Shah B, Ghauri B. Mapping urban heat island effect in comparison with the land use, land cover of Lahore district. *Pakistan journal of Meteorology*.
- [31] Demisse Negesse M, Hishe S, Getahun K. LULC dynamics and the effects of urban green spaces in cooling and mitigating micro-climate change and urban heat island effects: a case study in Addis Ababa City, Ethiopia. *Journal of Water and Climate Change*. 2024;15(7):3033-55.
- [32] Seun AI, Ayodele AP, Koji D, Akande SO. The potential impact of increased urbanization on land surface temperature over South-West Nigeria. *Current research in environmental sustainability*. 2022;4(Journal Article):209. doi:10.1016/j.crsust.2022.100142
- [33] Ayanlade A. Seasonality in the daytime and night-time intensity of land surface temperature in a tropical city area. *Science of The Total Environment*. 1 juill 2016;557-558:415-24. doi:10.1016/j.scitotenv.2016.03.027
- [34] Demisse Negesse M, Hishe S, Getahun K. LULC dynamics and the effects of urban green spaces in cooling and mitigating micro-climate change and urban heat island effects: a case study in Addis Ababa City, Ethiopia. *Journal of Water and Climate Change*. 26 avr 2024;15(7):3033-55. doi:10.2166/wcc.2024.662
- [35] Li X, Stringer LC, Dallimer M. The Spatial and Temporal Characteristics of Urban Heat Island Intensity: Implications for East Africa's Urban Development. *Climate*. avr 2021;9(4):4. doi:10.3390/cli9040051