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The Dynamics Of Land-Use/Land-Cover And Land Surface Temperature Changes In The Greater Accra Metropolitan Area, Ghana 1986-2020.

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Abstract:
Background*: Studies on the extremely high temperatures in towns and cities have become relevant because of the attention researchers have been paying to rural-urban temperature differences resulting from land-use/land-cover changes in the latter. Over the years, Ghana has experienced rapid urbanization primarily due to industrialization, migration and the extension of villages into towns, and towns into cities. The end result has been the creation of very temperatures in the built-up areas and their attendance health implications. Examined in this paper are the dynamics of land-us/land-cover and land surface temperature changes in the Greater Accra Metropolitan Area in Ghana during the period 1986-2020.*
Materials and methods*: Landsat Satellite imageries captured for the years 1986, 2002, 2011 and 2020 were used to map the land-use/land-cover changes and their resultant land surface temperatures.*
Results*: The results show that land surface temperatures of the area increased in space and intensity mimicking the rates at which the vegetation cover either thinned, grew dense, or disappeared. Much of the original vegetation cover that the area had 1986 was removed so that only remnants of the original vegetation remained in river valleys in 2020. The built-up area which also stood at 3872097 sq. km in 1986, had spread to cover 9721798 sq. km in 2020. The maximum and minimum temperatures rose from 30.12 ºC to 40. 06 ºC, and 20.88 ºC to 24,85 ºC respectively, during the period, echoing or reflecting the changes that occurred in the land cover.*
Conclusion*: The Land-us/Land-cover change maps show that much of the vegetation which originally covered the area has been altered so that remnants of the original vegetation are now found mainly in the valleys of the Densu River and its tributaries. The Land Surface Temperature maps show the phenomenon to have grown in time, space, and in intensity following the direction and the rate the vegetation cover was cut down to be replaced with concrete materials.*
Key Words*: Urbanization, Industrialization, Land-use/Land-cover change, Land surface temperature change, Dynamics and Reflecting.*

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I. Introduction

The Greater Accra Metropolitan Area (GAMA) suffers from recurring high temperatures. Very often, extremely high temperatures lead to intense human suffering and major economic problems. This area (Figure 1) which is the most densely populated, and is inhabited by over 2,514,000 people, is the most urbanised, heavily industrialised, and the main commercial centre in Ghana (Ghana Statistical Service 2020). All these characteristics of the metropolitan area have contributed to produce intense thermal or anthropogenic heating, which has been augmented by free insolation at the bare surfaces created by the inhabitants in the built-up areas and at the open vegetation surfaces probably created through the bush farming system. Extreme land surface temperatures (LST) in built-up areas in metropolis, popularly called urban heat islands (UHIs) are phenomena visualized as domes of stagnant warm air located directly above heated surfaces that coincide with heavily populated, industrialized and construction areas (Tzavali, Paravantis, Mihalakakou, Fotiadi & Stigka, 2015, & Olawoyin 2022). These UHIs are closely related to urbanization, and have been studied over a long period of time. Studies on LSTs in the developing countries, especially in Africa, have incidentally become relevant because of the great attention researchers have paid to rural-urban temperature differences resulting from land-use/land-cover change. For example, Mukhelif, Ammar and Joobri (2016) have observed that cities receive higher thermal heating than rural areas because the former typically have surface materials which have lower albedo than the surfaces in rural settings. They opine that high thermal capacity of urban or city areas, and lack of evapotranspiration through which plants usually dissipate heat, result in the strong thermal heating in towns and cities. The authors support their argument with the assertion that urban areas lose the low albedo of plants that are abundant in the rural areas but thin or cut down in the settled areas. Several other studies have posited that the concentration of dense population, factories and buildings in settlements, helps to produce enough thermal heating that increases the already high temperatures caused by strong insolation in urban areas. Nuruzzama (2015), for example, has observed that as the concentration of human beings is often prominent in city centers, the release of CO_2 is tremendous in such areas, because that gas stores heat, thereby increasing city temperatures.

In order to make available land for construction in Ghanaian cities such as Accra, Cape Coast and Takoradi, vegetation is wiped out on massive scales. But lesser trees mean lesser cooling efficiency in these urban areas. Trees intercept part of the incoming solar radiation, and also take in CO_2 during photosynthesis, thus keeping the temperature of the surroundings cool (Akbari et al; 2001). When the vegetation (in the city or countryside) is wiped out, the efficiency of the cooling system is completely removed, leading to the development of very high surface temperatures. Land-use/land-cover changes control thermal conditions in urban and rural areas (Xian and Crane, 2006). Roth (2008), for example, has observed strong relationships between land-use/land-cover change and city-centre thermal characteristics. The authors have observed that industrial locations of large settlements are the warmest, while vegetated, riverine, and littoral areas, have the coolest temperatures. The observations made by Addae, and Oppelt (2019); Yu, Enomah, Anchang, and Eduful (2018), show that significant changes in LULC is accompanied by population growth including the expansion of cities.

According to Mariwah, Osei, and Amenyo-Xa (2017), built-up areas gradually increase in size until they are the most common kind of land cover, drastically lowering the amount of vegetation in towns and cities. According to the authors, significant population expansion, together with increase in housing demand and rising commercial activities, drive changes in land cover across time period. Manu, et. al (2006) and Stem (2013) also say that land-use/land-cover changes, and the expansion in built-up areas, have mostly contributed to the rise in surface temperatures. Santana (2007) has therefore suggested that since different LULC characteristics change thermal conditions in large settlements, a good knowledge of LULC and LST necessary to augment urban planning resolutions on LST mitigations in towns and cities.

II. Materials and Methods

Study Location: The Greater Accra Metropolitan Area (GAMA Figure 1) is the study area. It lies between Latitudes 5º 29ʹ 14ʺ N and 5º 51ʹ 30ʺ N, and Longitudes 0º 31ʹ 39ʺW and 0º 5ʹ 41ʺ E. It is located in the southern part of Ghana next to the Gulf of Guinea. The area has a coastline of 63 kilometers that stretches from Kokrobite in the west to Kpone in the east.

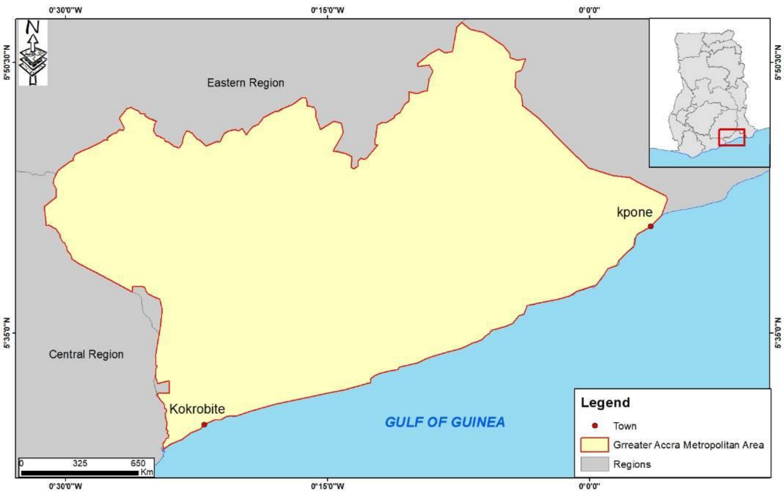


Figure 1: The Greater Accra Metropolitan Area (GAMA)

The dynamics of Land-use/Land-cover and Land surface temperature changes in the Greater Accra Metropolitan Area, Ghana 1986-2020.

The climate of the GAMA is dry tropical with the average temperature for February–March, the warmest period, ranging from 24 ℃ to 33 ℃, and 22 ℃ to 29 ℃ from June to September the coolest period. Day-light hours are almost constant (12 hours) throughout the year. Relative humidity during the dry period ranges from 65% at mid-day to about 95% at mid-night according to Ghana Meteorological Agency (Gmet, 2020).

Procedure methodology*:* Land-use/land-cover and surface temperature maps (Figures 3, 4, 5 and 6; and Figures 8, 9, 10 and 11) of the GAMA were generated (by computer) from a freely downloaded satellite data of four (4) cloud free days, from the United States (US) Geological Survey (USGS) website for the years 1986, 2002, 2011 and 2020. All the satellite data were captured during the particular days in December and January (the dry warm months) when most surface features exhibited similar reflectance, and the amount of moisture and cloud cover in the skies were minimal, thereby ensuring excellent capture of land-surface features. The first four satellite images show land-use/land-cover changes, while the last four show land surface temperature changes between 1986-2020. The data for the generation of the images were obtained by different Landsat sensors as shown in Table 1.

Table no 1: Shows Satellite images of the GAMA used for the study

Satellite	Sensor	Path/Row	Spatial Resolution	Acquisition Date	Source
Landsat 5	TM	193/56	30m	22/12/1986	USGS
Landsat 7	ETM+	193/56	30m	26/12/2002	USGS
Landsat 7	OLI/TIRS	193/56	30m	17/01/2011	USGS
Landsat 8	OLI/TIRS	193/56	30m	2/01/2020	USGS

Source: United States Geological Survey (2015)

Satellite Image Processing

The 8 downloaded remotely sensed satellite images were subjected to pre-processing procedure using the ArcGIS version 10.5 software. Radiometric correction was performed on the Landsat images to improve the accuracy of image classification. In this procedure, haze and noise were corrected for each band of the Landsat datasets. A geometric correction was done so that the (geometric) representation of the imageries could be as close as possible to the real world. The geometric correction included geo-referencing image, which was a process of relating images to specific map projections. The 8 Landsat imageries which were originally in the global coordinate system UTM zone 30/WGS 84 were transformed to the Ghana Metre Grid coordinate system. The spatial extent of the land in which the GAMA was located was huge so the images were obtained using the bounding polygon of the Greater Accra Metropolis. The subset images were registered geometrically to each other, before any image processing and analyses could be done.

Land use/cover mapping

The bands 1,2,3,4 of Landsat TM, EMT+ and bands 2,3,4,5 of Landsat OLI/TIRS were used to classify the land use/cover of the GAMA. Both the unsupervised and supervised classification algorithms were employed. The unsupervised classification was done to get the outline of the land-use/cover types. High-resolution images from Google Earth aerial photograph and ground-based knowledge, after the completion of detailed field survey, were used to select training samples for the supervised classification. The Maximum Likelihood Classifier was selected as the decision-rule for the supervised classification algorithms, while the categorizations of the LULC types were based on the United State Geological Survey classification scheme. The LULC maps were then reclassified into built-up areas, dense vegetated areas, open vegetated areas, and water (including wetlands or dambos) bodies (Table 2)

Table no 2: Shows Land-Use /cover classification types

Land use/cover	Characteristics
Built-up	These were the lands comprising the commercial, industrial and, residential areas, and the sites cleared for construction of community facilities such as lorry parks, and playing grounds.
Dense vegetation	These included the areas having dense vegetation with shrubs beneath.
Open vegetation	These were the areas having sparse vegetation. Such areas had few trees, shrubs, grasses and bare surfaces.
Water bodies	These areas were characterised by lakes, lagoons, ponds, canals and streams, mashes or dambos, fresh-water and their associated vegetation

Source: United States Geological Survey (USGS) Classification

Mapping of Land Surface Temperature/Urban Heat Islands

Conversion of Digital Numbers to Spectral Radiance: The Digital Numbers (DN) of the last four satellite images were converted to spectral reflectance to aid in the calculation of the Normal Different Vegetation Index *(*NDVI) and the LST. Conversion was done for the red and near-infrared and thermal bands of the different Landsat sensors using Equation (1) (Landsat Project Science Office, 2001). All values in the equation were obtained from the Landsat Project Science Office (2001) with reference to metadata that accompanied the Landsat Sensor. The Landsat Project Science Office equation is given as:

$\mathcal{L}\lambda = ((\mathcal{LMAX}\lambda - \mathcal{LMIN}\lambda)/(\mathcal{QCALMAX} - QCALMIN)) * (\mathcal{QCAL} - \mathcal{QCALMIN})\ \mathcal{LMIN}$ ……………………………………………(1)

Where $\mathcal{L}\lambda$ is the spectral radiance at the sensor's aperture, $LMIN\lambda$ is the spectral radiance scaled to $\mathcal{QCALMAX}$ $\mathcal{LMAX}\lambda$ is the spectral radiance scaled to $\mathcal{QCALMAX}$ is the $\mathcal{QCAL}$ is the $\mathcal{DN}$; $\mathcal{QCALMIN}$ is the minimum quantized calibrated pixel value (corresponding to $\mathcal{LMIN}\lambda$) in $\mathcal{DN}$ (0); and $\mathcal{QCALMAX}$ is the maximum quantized calibrated value (corresponding to $\mathcal{LMAX}\lambda$) in $\mathcal{DN}$ (255).

Conversion of Radiance to Brightness Temperature (BT): After the digital numbers (DNs) were converted to reflectance, the thermal bands of the sensors were also converted from spectral radiance to Brightness Temperature (BT) using thermal constants provided in the metadata of the satellite data. Equation 2 was used in the Raster Calculator tool in Arc Map to convert the reflectance to BT derived as follows:

$$BT = \frac{K2}{\mathrm{Ln}\,(K1/L\lambda) + 1} - 273.15 \quad \ldots\ldots (2)$$

Where K1 and K2 stand for the specific thermal conversion constant band from the metadata. To obtaining the results in degree Celsius, the radiant temperature was revised by adding the absolute zero (approximately -273.15˚F).

Calculation of the Normal Different Vegetation Index (NDVI*)*: The Landsat visible and near-infrared bands were used to calculate the NDVI. The estimation of the NDVI was essential since the amount of vegetation present was an important factor in detecting the areas covered by strong surface heating. The NDVI was used to infer the general vegetation cover. The calculation of the NDVI again was important because it indicated the proportion of the land covered by each vegetation type (Pv). The reflectance of each landscape type indicated the surface area it covered. Finally, the Emissivity (ε) which was also related to the Pv band was calculated as follows

Thus $$NDVI = \frac{NIR\ (Band\ 5) - R\ (Band\ 4)}{NIR\ (Band\ 5) + R\ (Band\ 4)} \quad \ldots\ldots (3)$$

Where: NIR represents the near-infrared band (Band 5) and R represent the red band (Band 4)

Calculation of Land surface Emissivity: The Land surface emissivity (LSE) had to be known to estimate the LST because the LSE is a proportionality factor that scales blackbody radiance (according to Planck's Law) in the prediction of emitted radiance. It is the efficiency factor in the transmission of thermal energy from the surface into the atmosphere above. The determination of the ground emissivity was done as follows:

$\varepsilon\lambda = \varepsilon v\lambda Pv + \varepsilon s\lambda(1-Pv) + c\lambda$ ………………………………………………. (4)

Where: εv and εs are the vegetation and soil emissivity respectively and c represent the surface roughness (c=0 for homogeneous and flat surface) taken as a constant value of 0. 005.

Calculation of Landsat Surface Temperature (LST)

The radiant surface temperatures for the four imageries from the 1986, 2002, 2011 1QWEQ and the 2020 satellite imageries were corrected employing emissivity values derived from equation 4 and using the equation:

$\mathcal{LST} = T_B/(1 + (\lambda\,\mathcal{T}_B/\mathcal{P})1n\varepsilon$……………………............................. (5)

Where $\mathcal{LST}$ is land surface temperature (in Kelvin); $\mathcal{T}_B$ is radiant surface temperature (in degrees Kelvin); λ is the wavelength of the emitted radiance ($11.5\mu m$); $\mathcal{P}$ is $\hbar \times c/r$($1.438\times 10^2 m\mathcal{K}$)); $\hbar$ is Plank's constant (6.26×10^{-34} J_S); c is the velocity of light (2.998×10^8 m/sec); r is Stefan Boltzmann's constant (1.38×10^{-23} J K^{-1}), and ε is emissivity. Finally, the LST values were converted to degree Celsius by subtracting 273.15 from the value derived in equation (5) (Artis and Carnahan, 1982). Figure 10 is the flow-chart showing the links between all the elements calculated.

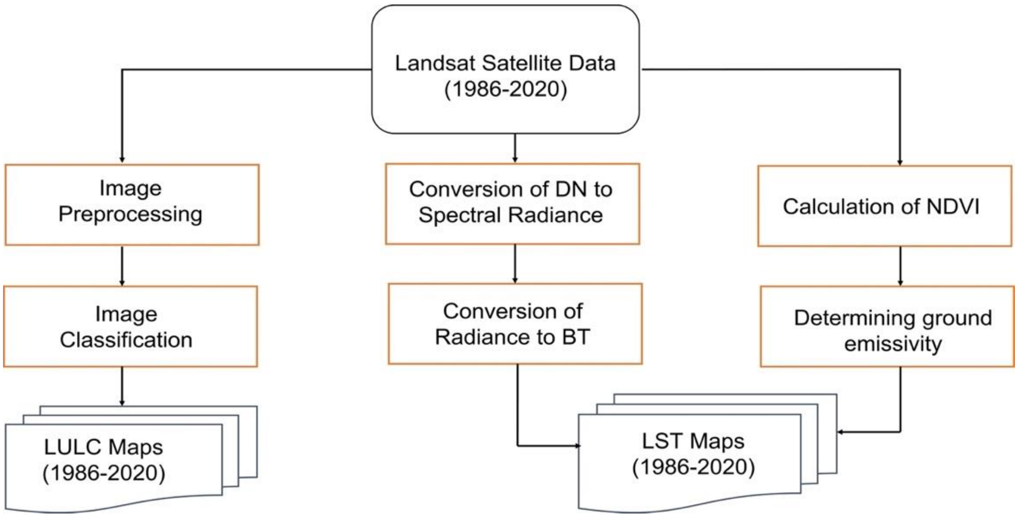


Figure 2*:* Flow chat for calculating (LST) in the GAMA.
Source: Author's construct, 2020.

III. Results

The dynamics of land-cover changes and urban growth in the GAMA 1986 – 2020

The Normal Difference Vegetation Index (NDVI) was employed to group land cover into types. The higher the NDVI values (i.e., >0.2), the denser the vegetation cover was. Conversely lower NDVI values ($-0 <$), indicate that the surface was either bare, occupied by bare soils, buildings, and so on. Consequently, the higher the NDVI values were, the lower were the Urban Surface Temperature (UST). The ground cover on each satellite imagery (Figures 3 - 6) was classified into four surface-cover types in order to ascertain the land-use/land-cover shifts, and urban growth in the GAMA, between 1986 and 2020 (Table 3)

Table no 3: Surface cover types in the GAMA in sq. Kilometers

LULC	1986	2002	2011	2020
Water bodies	33.714	44.7057	41.9868	36.4581
Dense vegetation	589.239	166.1517	31.1094	14.5962
Open vegetation	477.8523	889.3845	721.035	464.7996
Built-up	387.2097	387.7713	693.882	972;1798
Total	1488.013	1488.013	1488.013	1488.034

Source: satellite imagery

Land cover types in the GAMA in 1968

Much of the land in the north, west and south-western parts was occupied by dense and open vegetation in 1986 (Figure 3). Dense vegetation was located along river valleys in the north-west, and in the extreme north; the rest of the vegetation was open. Several farmsteads were located in the vegetated areas. Built-up area occupied much of the south along the coast. Isolated open vegetation was located in the built-up areas. Water bodies comprised the Weija Lake or Reservoir in the south-west, and the Pambrose marshland or *dambo* located some few meters from the sea in the south-west. There were a few water bodies along the eastern coast. Out of the total surface area of 1488.013 sq. km (Table 3) in the GAMA in 1986, water bodies occupied only 33.714 sq. km (or 2. 26 %). Dense vegetation covered an area of 589.239 sq. km (39.5%), while open vegetation took 477.8523 sq. km, (32.1%), and built-up area had 387.2097 sq. km (26%) of land.

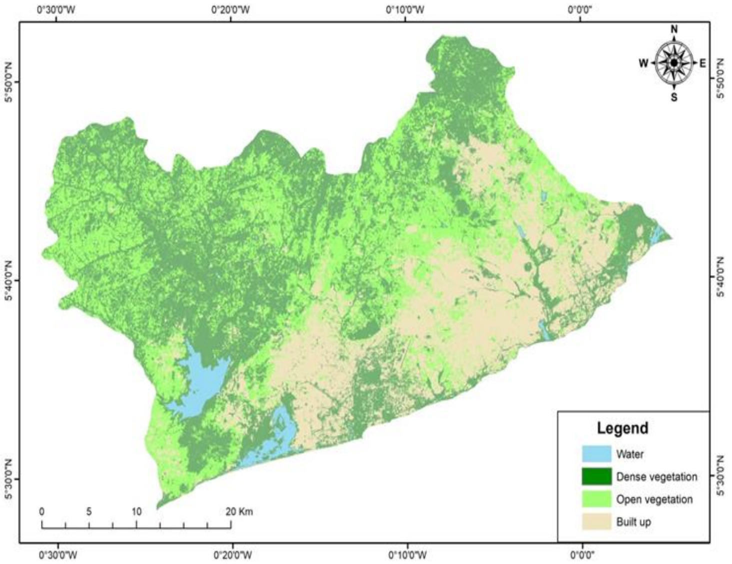


Figure 3*:* Land cover types in the GAMA 1986
Source: Satellite imagery.

Land Cover types in the GAMA by 2002

Sixteen years later in 2002 (Table 3, Figure 3), much of the dense vegetation had been reduced to open vegetation. The areas having dense vegetation in that year were the extreme north, and along river valleys, especially the Densu River and its tributaries, and the south–west. Isolated dense vegetation was scattered inside the open vegetation. Open vegetation occupied much of the interior, the west, south-west and the east of the area. Water bodies had increased in size because of the reduction in the dense vegetation. The Weija Lake which was probably hidden by thick vegetation, was now exposed, and extended; so also, was the Korle Lagoon whose location along the coast to the south was exposed and increased in size probably due to increased runoff that added more water to the lagoon. The Pambrose marsh-land or dambo (marsh-land) is now turned into a big pond. The built-up area too had increased in area, with much of the central-coast-land to the west and the east, occupied.

As shown in Table 3, the 2002 statistics indicates that water bodies increased in size by 10.99 sq. km (0.7%), from the 1986 figures. Dense vegetation was reduced by 423.0873 sq. km (28.4 %<), while open vegetation increased in size by 411.5 sq. km (27.6%). There was a slight increase of 0.56 sq. km (0.037%) in the area occupied by built-up area.

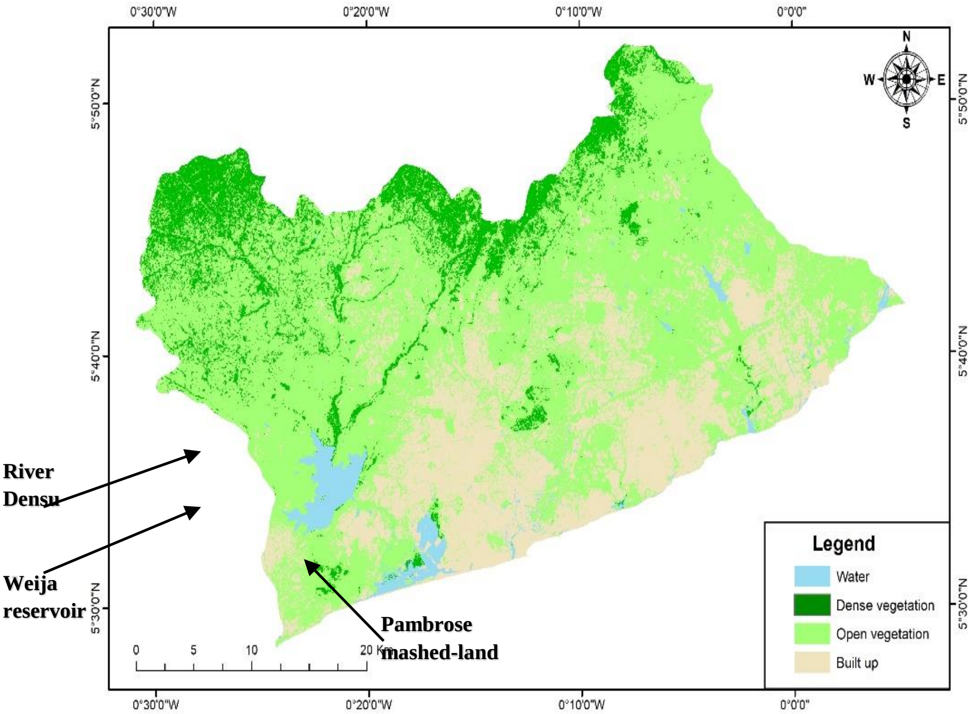


Figure 4: Land Cover types in the GAMA 2002
Source: Satellite imagery.

Land Cover types in the GAMA by 2011

In 2011, much of the dense vegetation had given way to open vegetation (Figure 5). The areas then having dense vegetation, were the far north-west, central north and north-east of the GAMA. Open vegetation had also reduced in area because much of the land had been cleared of its vegetation for settlement. The area of water bodies had decreased in size, even though other water bodies such as the Kpeshie Lagoon which hither to, were covered by dense vegetation were visible because the vegetation cover had been removed. The decrease in water bodies was probably due to the fact that increase in population led to a high demand for land (for construction of houses) and therefore people started sand-filling the land along river banks to construct houses. The dense vegetation that occupied the south-western part of the Weija Lake was cleared and replaced by buildings. The Korle Lagoon, whose extension was along the coast to the south, became more exposed, and the little dense vegetation that was located around the Pambrose dambo in 2002, had been reduced to open vegetation.

Built-up area in 2011 was extended, with much of the central coast and the interior occupied. The (built-up) area now extended along the entire coast from the south-west to the east with some few scattered vegetation here and there. The area occupied by water bodies in 2011 had declined to 41.9868 sq. km (2.8%). Dense vegetation occupied an area of 31.1094 sq. km (0.18%), while open vegetation occupied 721.035 sq. km (48.4%) of land, and built-up area took 693.882 sq. km (46.6%).

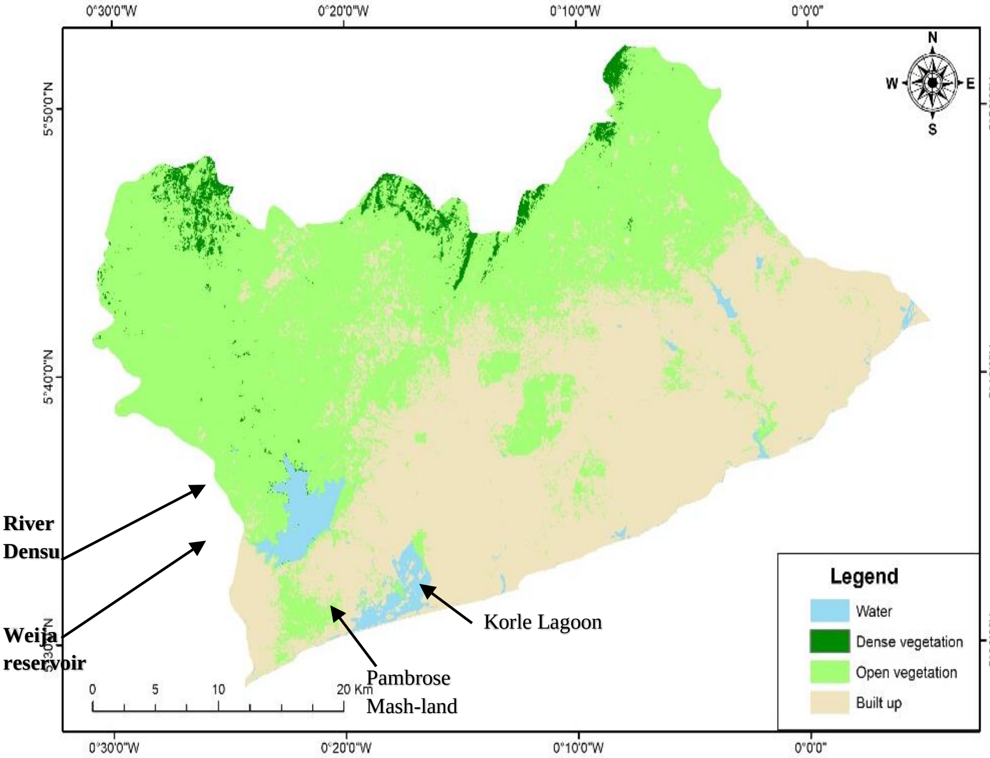


Figure 5: Land cover types in the GAMA 2011
Source: Satellite imagery.

The above statistics (Table 3) indicates that the area of water bodies which was 44.7057 sq. km (3%) in 2002, had reduced to 41.9868 sq. km (2.8%) in 2011, showing 2.7189 sq. km (0.18%) in reduction, while dense vegetation reduced in area from 166.1517 sq. km (11.1%) in to 31.1094 sq. km (0.18%) during the same period, indicating a drastic decrease of 135.0423 sq. km (9%). Open vegetation whose area increased tremendously between 1986 and 2002 was further reduced by 168.3495 sq. km (11.3%) to 721.035 sq. km. in 2011. Built-up areas which occupied a land-surface of 387.7713 sq. km (26%) in 2002 had increased astronomically to 693.882 sq. km (46.6%) in 2011 at the expense of vegetation.

Land Cover types in the GAMA by 2020

By the year 2020 (Figure 6), much of the GAMA had been converted into built-up areas. The Korle Lagoon, the Pambrose dambo or marsh-land, the Weija Reservoir, and the Densu River and its tributaries had decreased in area and in volume because of urbanization (Figure 5). Some narrow bodies of water appeared along the coast to the east and west of the metropolis. The dense vegetation was drastically reduced to the extreme north and north-east. Open vegetation was located in the north-west along river valleys, and in the north-east. Several isolated open vegetation was scattered inside the built-up areas.

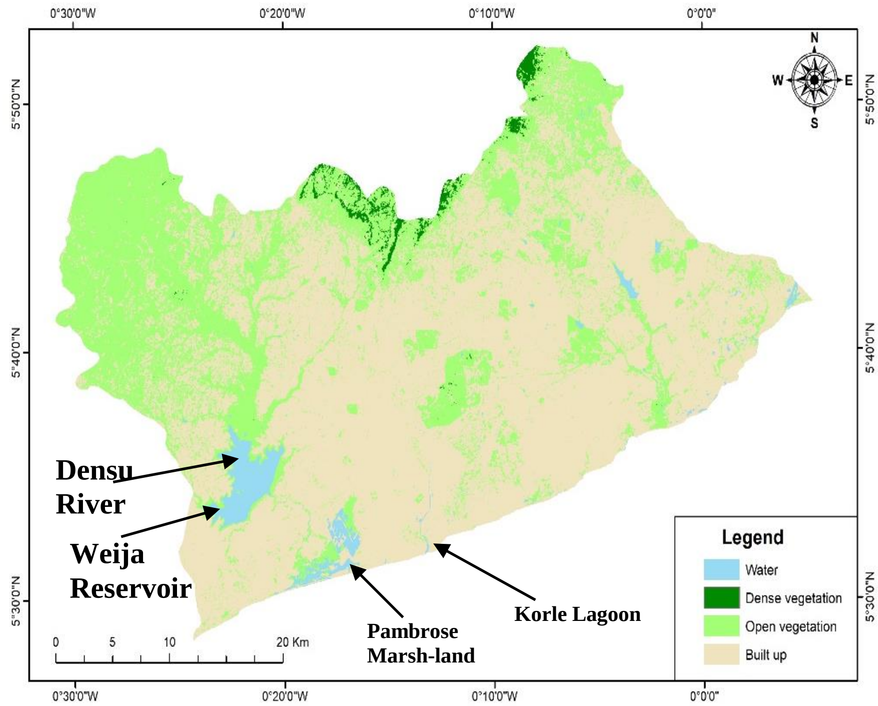


Figure 6: Land cover types in the GAMA 2020
Source: Satellite imagery.

The land-use/land-cover changes that took place in the GAMA between 1986 and 2020, demonstrate the extent to which humans can dynamically and dramatically change the natural cover of the earth. Whereas water bodies, and the vegetation cover reduced drastically in area from 2011 to 2020, built-up area which occupied 387.2097 sq. km in 1986 increased to 972.1798 sq. km in 2020 due to the massive increase in the built-up area. The clearing of vegetation (deforestation) paved way for more housing to accommodate the ever-growing population and development. Consequently, the surface cover which was replaced with man-made materials absorbed much more solar radiation, which certainly increased surface temperatures, and hence the creation and intensification of UHIs in the GAMA.

Dynamics of the changing surface temperature in the GAMA 1986-2020

Maximum, minimum and mean land surface temperature dynamics in the GAMA

Table 4 and Figure 7 show the maximum, minimum and the mean (i.e., max + min/2) land surface temperature (LST) changes from 1986 to 2020. The average maximum LST in 1986 was 30.12 ℃. It rose to 31.37 ℃ in 2002. In 2011 the value had risen to 38.75 ℃, and in 2020 it was 40.06 ℃. The astronomical rise (9.94 ℃) in the maximum land surface temperature in three decades clearly was due to the reduction in the vegetation cover, and to the massive increase in the built-up area (Table 14). This is particularly noticeable between 2002 and 2011 when the increase in the maximum LST was 7.38 ℃.

Table no 4: Shows land-surface temperatures (LST) in the GAMA (1986-2020)

Year	Mean	Maximum	Minimum
1986	25.2	30.12	20.88
2002	28.73	31.37	18.04
2011	29.32	38.75	21.34
2020	32.08	40.06	24.85

Source: US Geological Survey

Minimum land-surface temperature MLST of the GAMA 1986-2020

The 1986 minimum LST of GAMA was 20.88 ℃; it however decreased by 2.84 ℃ to 18.04 ℃ in 2002. In 2011, the value had increased to 21.34 ℃, indicating a rise of 3.3℃. In the next nine (9) years, the minimum LST rose to 24.85 ℃ (in 2020), showing a further rise of 3.51℃.

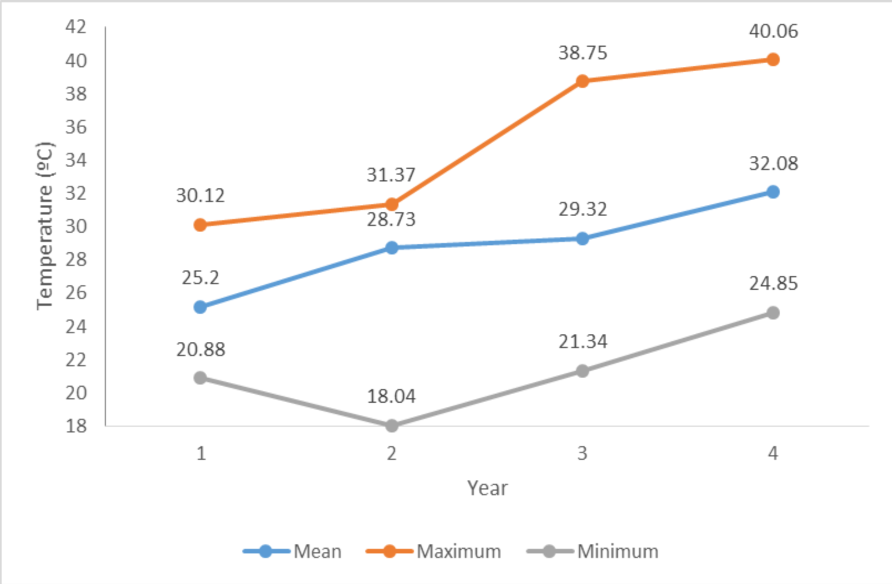


Figure 7: Mean, minimum and maximum LST from 1986 to 2020
Source: US Geological Survey

Mean Land Surface Temperature of GAMA 1986-2020

The average LST shows an increase from 1986 to 2020. In 1986 the value was 25.2 °C; by 2002, it had risen to 28.7 °C. In 2011 the value was 29.32 °C, and in 2020, it had risen to 32.08 °C. The rise in the average LST as observed in the maximum and the minimum LST, is certainly explained by the replacement of the surface vegetation cover with buildings and concrete surfaces which absorbed more solar energy, and hence gave out heat energy.

The dynamics of land cover and surface temperature changes in the GAMA 1986 – 2020

Table 6 and Figures 8, 9, 10 and 11 show the changes in land surface cover and the attendant temperature changes in the GAMA between 1986 and 2020. In 1986, 446.38 (30.0%) sq. km of land surface in the GAMA recorded less than 21 °C (<21 °C); a much larger surface 587.65 sq km (39.49%) recorded 22-27° and a similar surface also registered 28-33 °C. In 2002, 466.71 (31.36%) sq. km of the surface recorded less than 21°C, while 516.33 (34.70%) sq. km recorded between 22°C and 27°C, and 504.97 (33.94%) sq. km also recorded between 28-33 °C. In 2011 no surface cover recorded an LST value of less than 21 °C; 354.25 sq km recorded 22-27 °C, while 535.39 (35.98%) sq km registered 28-33 °C, and 40.21% (598.38 sq km) recorded 34-39 °C. The year 2020 happened to be the warmest during the 30-year period, with 160.52 sq km (10.79%) of the surface experiencing 22-27 °C LST, and 317.03 sq km (21.31%) recording 28-33 °C. Over five hundred and forty-eight square kilometers (548.30 sq km or 36,85%) recorded 34-39 °C LST, and 462.17 sq km (31.06%) of the surface of GAMA experienced over 40 °C LST.

Table no 5: Shows LST-classes with their respective area covered in sq. km^2 *GAMA 1986-2020*

Year	<21 °C	22-27°C	28-33°C	34-39°C	>40°C
1986	446.38 (30.0 %)	587.65 (39.49 %)	587.65 (39.49 %)	-	-
2002	466.71 (31.36 %)	516.33 (34.70 %)	504.97 (33.94 %)	-	-
2011	-	354.25 (23.81 %)	535.39 (35.98 %)	598.38 (40.21 %)	
2020	-	160.52 (10.79 %)	317.03 (21.31 %)	548.30 (36.85 %)	462.17 (31.06 %)

Source: Satellite imagery**.**

Land surface cover and temperature (LST) dynamics in the GAMA in 1986

The 1986 image shows densely vegetated and water bodies recording relatively moderate surface temperatures (Figure 8). The minimum surface temperature, recorded over the densely vegetated areas and water bodies was 20.88 ºC. Built-up areas in the south-east had rather high maximum temperatures. Scattered hotspots occurred in the interior open-vegetated areas. Such hotspots coincided with the locations of isolated farm-steads or settlements. The land to the extreme north-east, north-west, and some parts of the south-west where land surface temperatures were 20.88 ℃, were devoid of any hot spot. These were the areas that were covered by dense vegetation, rivers or open-water surfaces and dambos. The hot spots where land surface temperatures were more than 30.12 ℃ were located in the southwest-northeast direction. In 1986, 446.38 (30.0%) sq. km of land surface in the GAMA recorded less than 21 ℃ (<21 ℃), while 587.65 (39.49%) sq. km recorded 22-27 ℃, and another 587.65 sq. km of the land surface recording the same temperature value.

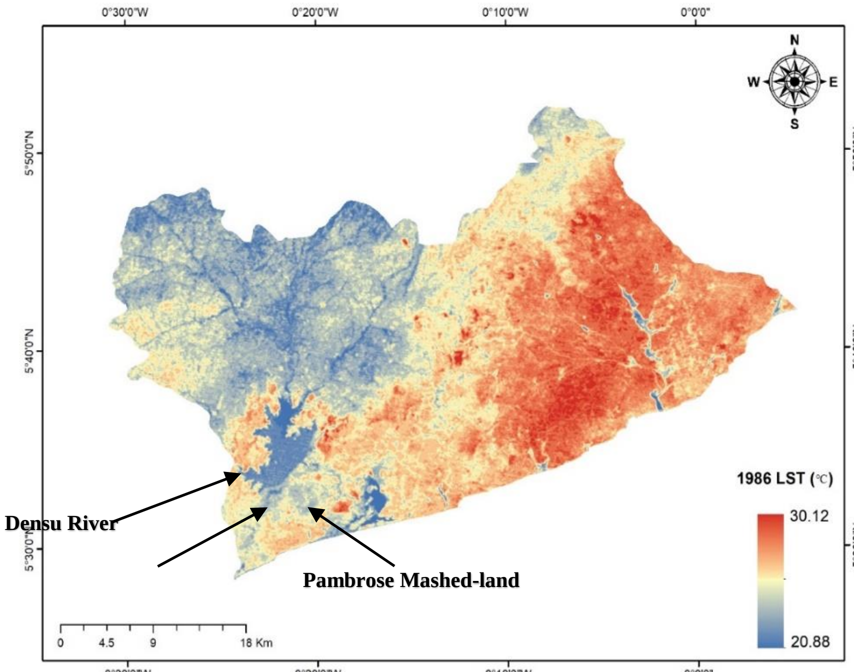


Figure 8: Land surface temperature in the GAMA 1986
Source: Satellite imagery, 2020.

Dynamics of land surface cover and temperature (LST) changes in the GAMA in 2002

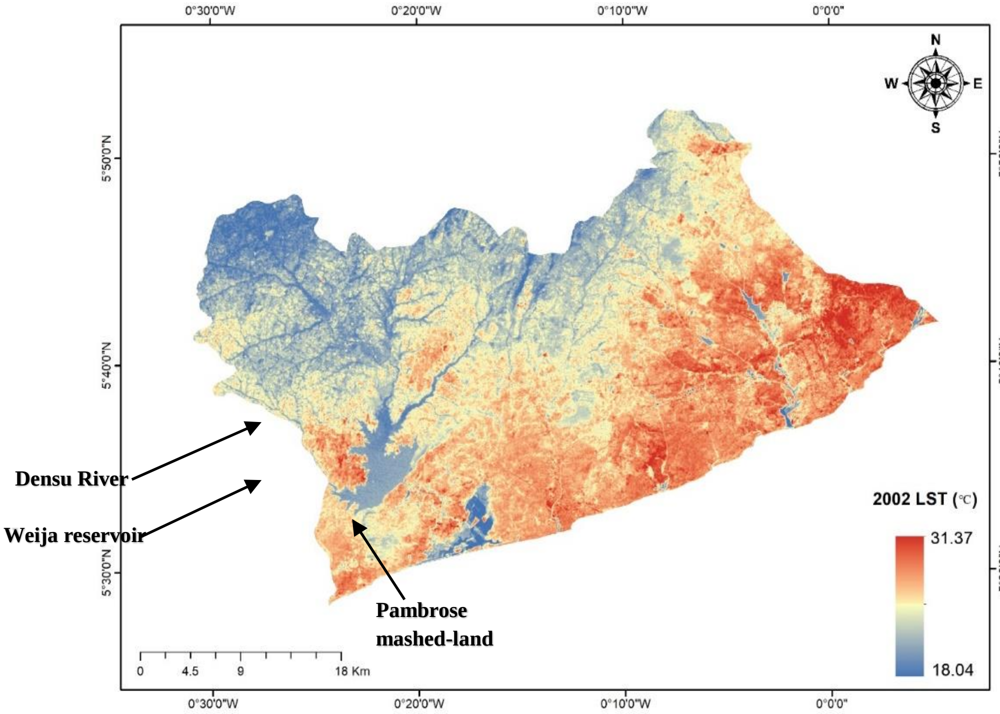


Figure 9: Land surface temperature in 2002 in the GAMA
Source: Satellite imagery, 2020.

The maximum LST in 2002 has increased while the minimum value dropped by 2.84 ºC. In that year, low temperature readings were located in the densely vegetated areas, along river valleys, and over other water bodies. Stretching from the north-east to the south-west were the hotter surfaces, with the highest temperatures reaching 31.37 0. In 2002, 466.71 (31.36%) sq. km land surface recorded less than 21℃ temperatures, while 516.33 (34.70%) sq. km (of the land surface) recorded between 22℃ and 27℃, and 504.97 (33.94%) sq. km witnessed between 28-33 ℃ temperature.

Dynamics of land surface cover and temperature (LST) changes in the GAMA in 2011

As the years progressed (2011) the GAMA witnessed a significant increase in LST, especially in the built-up areas along the coast and much of the interior. The heated areas were centered in many places such as Madina, Nima, Abeka, La, Teshie-Nungua and Ashaiman-Tema industrial and Harbour City area (Figure 9) where the LST value reach 38.75℃. Even then, few areas - along river valleys in the north-west- in the north-east, and over water bodies in the south-west had a minimum LST value of 21.34 ℃. No surface cover type recorded an LST value of less than 21 ºC. Over three hundred and fifty-four square kilometers (354.25 sq km, or 23.81%) of the area recorded between 22-27 ºC, while 535.39 sq km (35.98%) recorded 28-33 ºC and 40.21% (598.38 sq km) recorded 34-39 ºC LST.

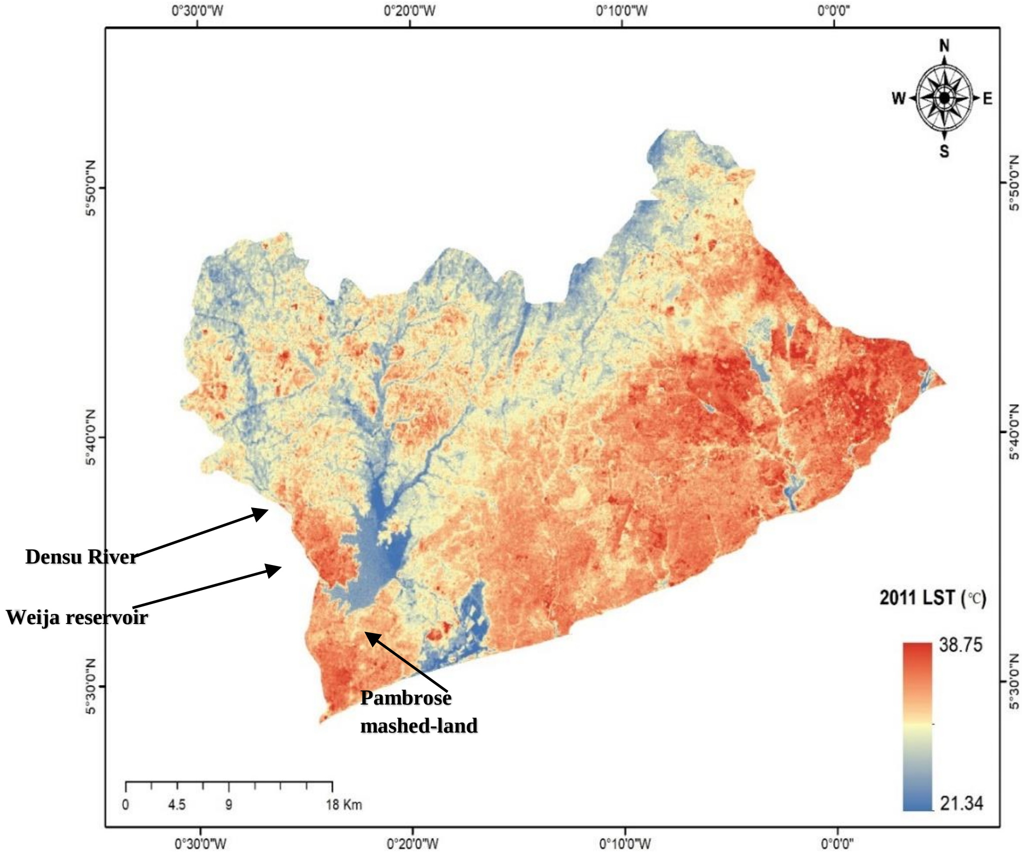


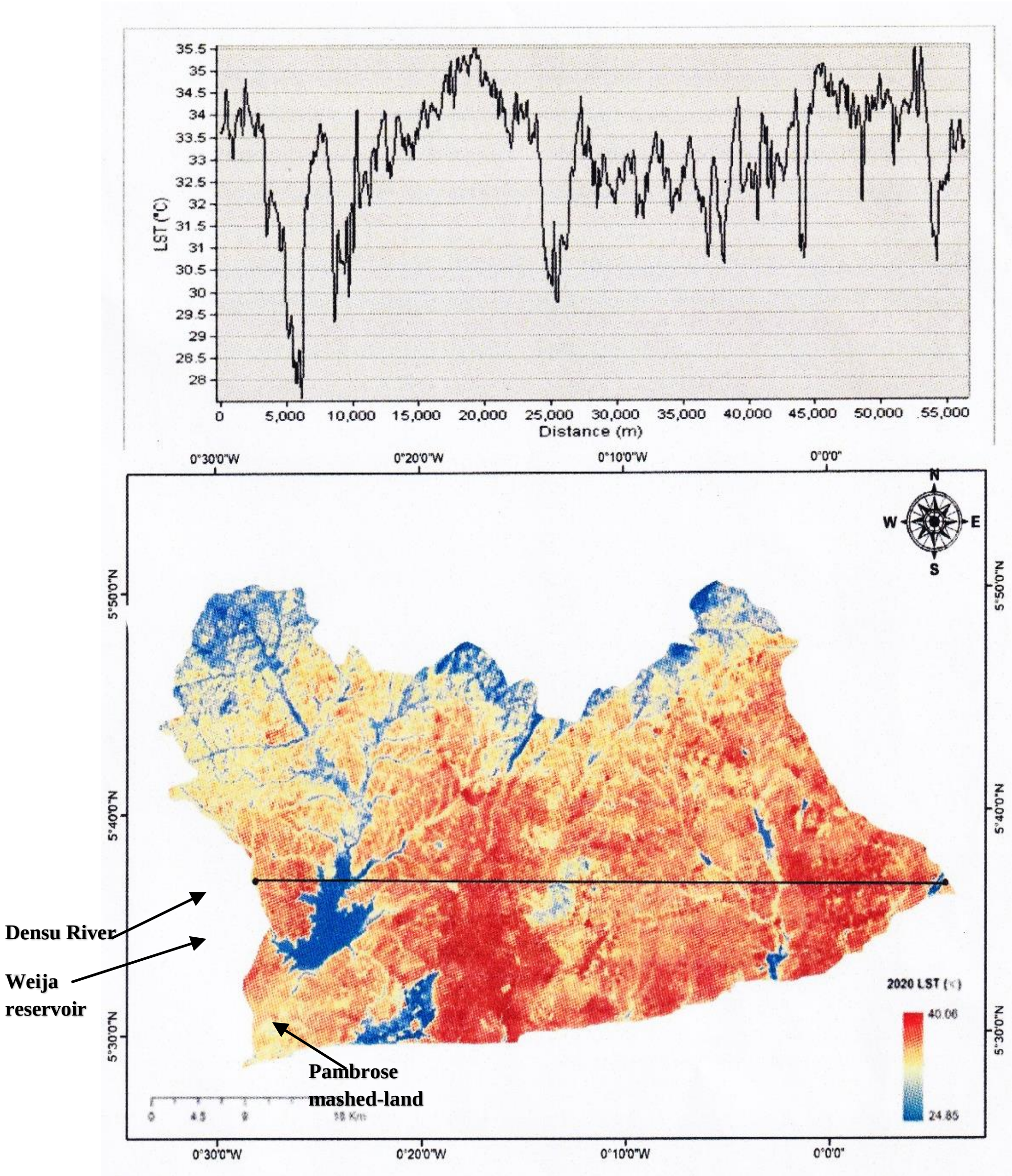
Figure 10: Land surface temperature in the GAMA 2011
Source: Satellite imagery, 2020

Dynamics of land surface cover and temperature (LST) changes in the GAMA in 2020

The year 2020 recorded the highest minimum and maximum LST values (Figure 20). The extreme north-east, north, and the north-west along river valleys, and over open water surfaces recorded the lowest LST of 24 ℃. The rest of the GAMA recorded high maximum LST that soured to over 40 ℃ in the east, along the coast and in the central west. No surface recorded an LST of less than 21 ºC. Just a little over one hundred and sixty square kilometers (160.52 sq. km or 10.79 % recorded an LST of 22-27 ºC. An increasing surface (317.03 sq km or 21.31%) area recorded 28-33 ºC LST. Some 548.30 sq km (36.85%) of the surface recorded 34-39 oC LST, and for the first time, 462.17 sq km (31.06%) registered an LST of over 40 ºC.

A cross section of the 2020 LST portrays the nature of the phenomenon in the GAMA. Instead of the dome-like feature associated with mid-latitude LST of towns and cities, the phenomenon in the GAMA, a tropical metropolis, is like a dissected plateau with the lower values coinciding with the locations of open water bodies and the much-heated places coinciding with heavily populated areas.

Figure 11: Land surface temperature in the GAMA 2020



Source: Satellite imagery, 2020

IV. Discussion

A comparison between land-use/land-cover changes, and the LST changes in the GAMA during the period 1986-2020 demonstrates the extent to which humans can alter land cover, and increase surface temperature of their surroundings. The present study demonstrates that when and where more and more land surfaces in the GAMA were converted into farm-lands and into urban settlements in the successive years, the LST of the affected surfaces also increased in area and in intensity. This reason probably explains the absence of any surface registering temperatures beyond 33 ℃ in 1986 and 2002, because much of the surface cover by then, had not been degraded. In 2011 when urbanisation was in full swing (Olawoyin, 2023), no surface area recorded less than 21 ℃ temperature. On the other hand, some surfaces began to record temperatures of 34-39 ℃. In 2020, urbanisation was prominent; more surfaces were cleared, and river valleys and dambos were filled for the creation of market places, and the construction of roads, office buildings, housing and motor vehicle stations. Most of the materials used for the construction of these facilities acted like black bodies that absorbed maximum solar radiation, and emitted terrestrial radiation which caused the intense thermal heating in much of the GAMA in the succeeding years.

The lower surface temperatures over the water surfaces and vegetation in 2002 could be explained by first, increased evapotranspiration, a cooling process from the now increased water bodies, and vegetated surfaces, and second, by the high albedo of the vegetation cover that resulted in low insolation at the surfaces beneath the vegetation cover. In the built-up areas, direct solar radiation, and thermal heating by factories, houses, motor-vehicles, bare surfaces and building materials that easily absorb solar radiation and gave up infrared radiation, accounted for the creation of the high temperatures in places.

The spread and intensification in the phenomenon clearly were anthropogenically caused. The rapid increase in population, urbanization and industrialization, and of course, the replacement of the vegetated areas with artificial materials that behaved like black bodies, certainly caused the LST to grow in intensity and in area with time. It is interesting to note that the high temperature spread following human settlements. The 1986 surface temperatures exemplify the different thermal characteristics of the built-up areas, the water bodies, and the land under its natural vegetation cover. The built-up areas are associated with high surface temperatures, while water bodies and vegetation are associated with lower temperatures.

The anomaly in the temperature distribution is the drop in the minimum temperature from 20.88 ^{o}C in 1986 to 18.04 ^{o}C in 2002. The explanation of this anomaly is the increase in evapotranspiration from the forests and from the open water bodies. The maximum temperature on the other hand increased in intensity because of anthropogenic heating in the built-up areas, and thermal heating from the bare surfaces created by the inhabitants.

The 2011 and 2020 temperature increases follow the expansion of office and domestic buildings, increase in population, factories, and vehicular movement in the metropolis. The expansion of settlements to the north entailed the cutting down of more and more open and dense vegetation, and the return of the people to the north because of lack of accommodation in the south. Surface albedo decreased and the rate of evapotranspiration reduced drastically while insolation in the built-up and bare surfaces increased. At the same time anthropogenic heating increased tremendously over a now vast open surface. Surface temperature in the GAMA would certainly increase in area and intensity if the negative anthropogenic factors are not stopped.

V. Research implications

The result of this work is an eye opener to government, politicians, planners, rural and urban dwellers, about the causes of LST in towns and cities in the country. Based on the key findings, the following recommendations are made. Government must alert the Planning Department of the District Assemblies in the country, in particular the GAMA, where high temperatures are detected, to grant permit only for buildings that will have retrofitting materials to make them more energy efficient. Buildings must be painted white to increase albedo. Government, through the Electricity Corporation of Ghana (ECG), must deploy more sustainable energy system such as solar panels in buildings to reduce the use of thermal plants employed by the dwellers in high density areas to provide electricity to power their air conditioners. Government through the Wetlands Conservation Authority of Ghana should alert city planners to restore and maintain wetlands, mangrove swamps and salt marshes, and also create ecological sanctuary in the metropolis. Evapotranspiration from dense vegetation and wetlands has the capacity to equalize temperature differences and to play important role in mitigating urban heating effect. Implementation of tree-planting in private homes, buildings and surroundings, and in public places, should be encouraged. Air conditioners in buildings exacerbate urban heat as they constantly release hot air into the ambient atmosphere. Owners of big buildings such as hotels and shopping centers in the GAMA can recycle the pumped-out hot air by adding heat exchangers that recycle heat back to washrooms to heat bathing water.

VI. Conclusion

The present study investigated the dynamics or relationship between land-use/land-cover changes, and surface temperature changes in the Greater Accra Metropolitan Area. The first four LULCC maps for the years 1986, 2002, 2011 and 2020 show that much of the vegetation which originally covered the area has been altered so that remnants of the original vegetation are now found in 2020 mainly in the valleys of the Densu River and its tributaries. The next four surface temperature maps show the phenomenon to have grown in time, space, and in intensity following the direction and the rate the vegetation cover was cut down to be replaced with concrete materials. One important feature of the LST in the GAMA was observable. Unlike the cold temperate cities where LSTs are dome-shaped, the LST in the GAMA appeared as a dissected plateau along the coast from the west to the east, and hot surfaces scattered in the rest of the area indicating the locations of the several settlements. The indentations in the LST were the ‘’canyons’’ showing the remnants of the much-encroached marshlands in the housing estates.

Hence, the study recommends that Government must alert the Planning Departments of the Districts Assemblies in the GAMA where the LSTs were detected to be high, to grant permit only for buildings that would have retrofitting materials to make them more energy efficient. Buildings must also be painted in white colour to reflect much of the incoming solar radiation to reduce the warming of buildings. Again, the Government through the Wetlands Conservation Authority should alert planners to restore and maintain wetlands, mangrove swamps, and salt marshes, and also create ecological sanctuaries in the GAMA.

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