Urban Land Surface Temperature and Vegetation Correlation in the Kumasi Metropolis

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Abstract: Urban heat is considered as a worrying issue in cities because of the unbearable feelings associated with heat especially on sunny days. Urban heat is not as a result of any one time event but a chain of processes associated with land use activities such as infrastructure development that replaces the green vegetation. This paper investigated how land surface temperature has changed in the Kumasi Metropolis in 10 years from an environment of low temperature to much warmer land surface temperature due to the loss of trees in the city. The objectives of the study were to assess the extent of Land Surface Temperature (LST) in the metropolis, determine the kind of correlation that exist between Land Surface Temperate and vegetation health and examine the extent to which vegetation has influenced the city temperature. Multiple methods were used to calculate Land Surface Temperature (LST) such as converting the digital numbers of Landsat 2009, 2015 and 2019 images to radiance, top of brightness temperature and at-sensor brightness temperature using the Plank's inverse function. NDVI analysis was done by subtracting the near infrared bands from the red band, divided by addition of the near infrared band to the red Band. Study results showed a linear increase in LST from an average of about 18°C to 31°C. The NDVI result showed decline in vegetation cover as such the correlation analysis was a negative correlation showing places of high temperature had minimal vegetation cover while places of low temperature had more vegetation cover.

Keywords, Correlation, Land surface, Temperature, Urban heat, Vegetation, Vegetation index.

1. INTRODUCTION

Land Surface Temperature provide important information on surface physical properties such as heat as a result of many environmental processes (Dousset & Gourmelon 2003; Weng, Lu & Schubring 2004;Gusmão *et al*., 2013). The surface temperature of land is determined by measurement of heat emission from land surfaces using remote sensing techniques (Kumar, Bhaskar & Padmakumari, 2012). The relative warmth of cities can also be estimated by measuring the air temperature, using land-based observation stations or measuring air temperature using temperature sensors mounted on cars, along various routes (Yamashita 1996).

Analysis of air temperature in different spatial environments show environments with trees usually have cool air temperatures while paved areas have high temperatures (Nichol & To, 2012). Vegetation cover improves transpiration and photosynthesis Jesus & Santana, (2017) while removal of the forest cover distorts radiation balance and alters the normal energy interaction between the earth's surface and the Earth's atmosphere (Corrêa *et al*., 2016). Reduction of green vegetation cover is regarded as the cause of gradual rise in urban air temperature in many cities of the world (Kumar *et al*., 2012). Vegetation is therefore seen as major factor that causes surface temperature changes on spatial and temporal scales (Fathian *et al*., 2015). Clearing of forest and wetlands for purposes of agriculture and other reasons have been sources of increased Land Surface Temperature (Mallick *et al*., 2008).

The conversion of vegetation to impermeable surfaces made of concrete influence the absorption of solar radiation, evaporation and storage of heat that alters the near-surface atmosphere of cities (Mallick *et al*; 2008). A rise in the surface temperature of urban lands above normal due to creation of paved surfaces has contributed to a phenomenon known as Urban Heat Island (UHI) (Ramachandra *et al*., 2012). Urban heat island is a climatic condition that is rapidly developing in cities of the world and can be measured or estimated using remote sensing image data. The construction of roads, buildings and pavements in place of the natural vegetation has been a major source of heat in cities coupled with industrial production processes (Ramachandra *et al*., 2012). Creation of artificial man made physical features such roads and pavements have lower albedo and high thermal conductivity and volumetric heat capacity compared to places that have trees (Molnar, 2016). Part of the urban heat is also generated through motor traffic movements and use of domestic energy for cooking, heating, cooling, which are anthropogenic sources of heat emission (Kumar, Bhaskar, &

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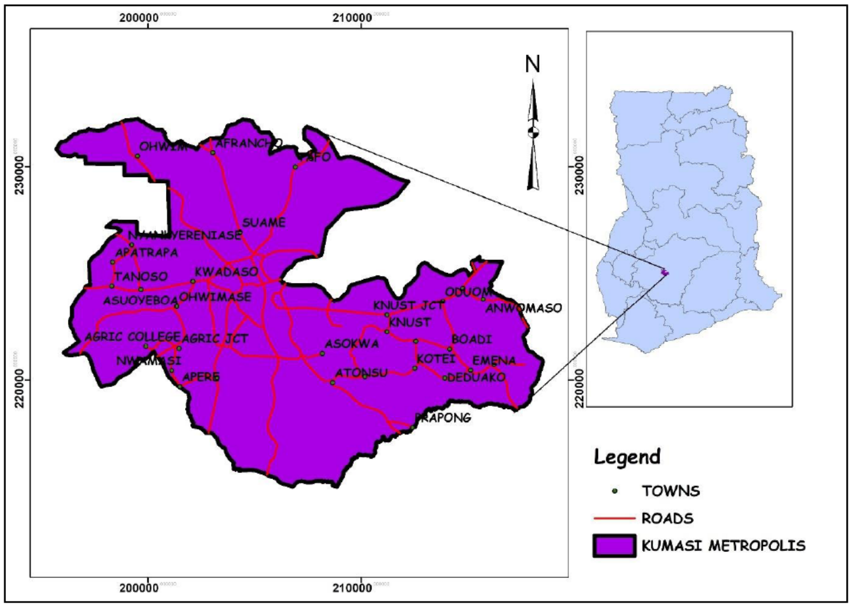

Figure 1: Map of Study Area.

Padmakumari, 2012).

Spatio-temporal data analysis of temperature in cities are done using models to understand the relationship between temperature and land use and land cover change in urban areas that were once covered with vegetation but now taken over by infrastructure development (Ramachandra *et al*., 2012).

Ghana is experiencing rapid urbanization as rural folks move to the cities of Accra, Takoradi, Kumasi, and Tema to seek for jobs and enjoy good social amenities (World Bank Group, 2015). Urbanization has contributed to reduction in green spaces even though the green spaces are important environmental asset to urban and rural areas (Mensah, 2014). Analysis of remote sensing data over a period of 30 years in the Kumasi Metropolis showed extensive land use and land cover changes from 1986 to 2016 where green areas were lost to built up areas by 54.6% (Abass, Adanu & Agyeman, 2018). This rapid urbanization is contributing to extraordinary urban heat (Koranteng, Simons, & Nyame-Tawiah, 2019). It is projected that, there is a high probability that by 2031 much of the existing limited vegetation in the Kumasi metropolis will be lost to built-up areas (Abass, Adanu & Gyasi, 2018).

In view of the rapid loss of tree cover which is expected to worsen in the future this study calculated the land surface temperature of Kumasi metropolis and correlated the results with vegetation to understand the nature of relationship.

2. STUDY AREA AND METHODOLOGY

Kumasi is the capital city of the Ashanti Region, an important commercial, industrial and cultural city regarded as the second largest city in Ghana. The city is located on a land area of 254 sq km. The city is divided into 10 main Sub-metros which are Asokwa, Bantama, Asawasi, Kwadaso, Nhyiaso and Oforikrom. The others are Suame, Tafo, Subin and Manhyia sub-metros (Ghana Statistical Service, 2002).

The topography is undulating and a geology characterized by middle precambrian rocks. The soil is silty clay loam and permeable resulting in fairly high runoff rates. The vegetation comprises moist semi-deciduous exotic tree species such as Ceiba, Triplochlon, and Celtis that make Kumasi the Garden City of West Africa (KMA, 2006).

The annual rainfall is around 1484 mm per year and temperature of 27.9 °C is considered the highest temperature that occurs in March and the lowest average temperature of 24.4 °C occurs in August (Anon., 2019).

2.1. Methodology

Estimation of land surface temperature was done by downloading Landsat ETM+ 2009, Landsat OLI 2015 and 2019 from the United States Geological Survey (USGS) website (Table **1**). Figure **2** shows methods followed to make the maps and graphs. Image data were geometrically and radio metrically corrected after which the images were sub-setted using the shapefile

Table 1: Data Types

	Acquisition Date	Satellite	Spatial Resolution	Sensors	Number of Bands
2009	15th November, 2009	Landsat 7	30 m	ETM +	7
2015	11th January, 2015	Landsat 8	30 m	OLI	11
2019	5th January, 2019	Landsat 8	30 m	OLI	11

of Kumasi Metropolis. The digital numbers of thermal infrared bands were converted to spectral radiance using a standard equation provided by Landsat user's hand book. The at-sensor brightness temperature was obtained from the spectral radiance using Plank's inverse function. The Normalized Difference Vegetation Index calculation was done by measurements of red and near-infrared reflectance which was done using the formula by (Jawak & Luis, 2015)

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where;

NIR = Near Infrared Reflectance

RED = Visible Red Reflectance

NDVI values ranges from –1.0 to 1.0. Values less than 0.1 indicate no vegetation such as rock, water,

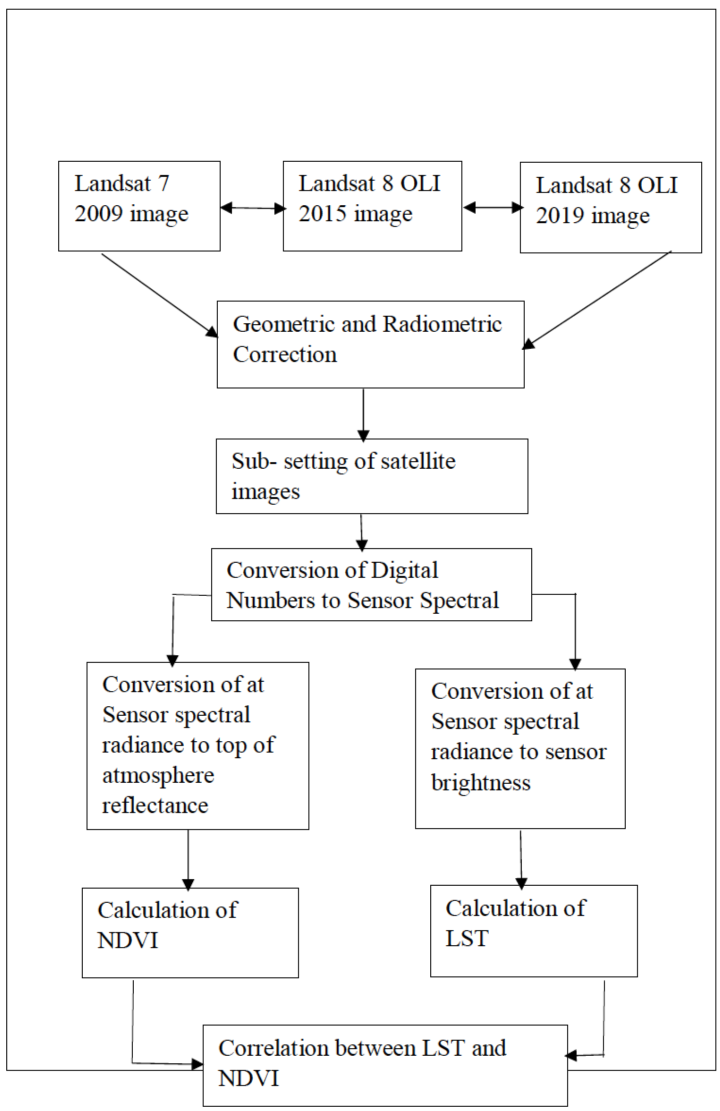

Figure 2: Methodological Framework for Image Analysis.

ice, snow and barren surfaces Fu and Burgher, (2015) while vegetated areas are in the range of 0.2 and 0.9 (Bustos and Meza, 2015).

The LST analysis was done by converting Digital Numbers of band 6 of Landsat 2009 image to radiance and band 10 of Landsat (2015 and 2019 images). A digital number is the pixel of an image that has a numerical value constituting the picture of the image. Radiance refers to the flux of energy (mainly irradiant or incident energy) per

Solid angle that leaves a unit surface area in a given direction.

This equation was used to convert the digital numbers of the three images to radiance units:

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

Where;

Lλ = spectral radiance at the sensor's aperture in watts per (meter squared * ster * μm)

QCAL = quantized calibrated pixel value in Digital Numbers

LMINλ = spectral radiance that is scaled to QCALMIN in watts per (meter squared * ster * μm)

LMAXλ = spectral radiance that is scaled to QCALMAX in watts per (meter squared * ster * μm)

QCALMIN = minimum quantized calibrated pixel value (Corresponding to LMINλ) in DN

QCALMAX = maximum quantized calibrated pixel value (Corresponding to LMAXλ) in DN.

The radiance units were later converted from at-sensor spectral radiance to At sensor brightness using the formula:

$$T = K2/Ln(\frac{k1}{L\lambda} + 1$$

Where;

T = Effective at-sensor brightness temperature (K)

K2 = Calibration constant 2 (K)

K1 = Calibration constant 1 (W/m2 sr μm)

Lλ = Spectral radiance at the sensor's aperture (W/m2 sr μm)

Ln = Natural logarithm

Calculation of reflectance which is a function of the incident angle of the energy, viewing angle of the sensor, spectral wavelength, bandwidth, and nature of the object were done using the formula below

$$\rho\lambda = \pi * L\lambda * d^2/ESUN\lambda * COS\theta_S$$

Where;

Pλ= Planetary TOA reflectance (unit less)

Lλ = Spectral radiance at the sensor's aperture.

D = Distance from the earth to the sun in astronomical units (AU).

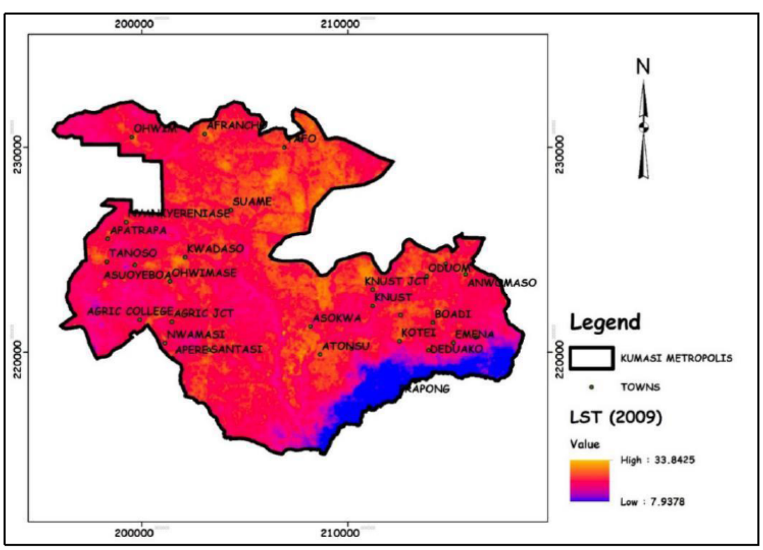

Figure 3: Land Surface Temperature map 2009.

π = 3.14159

ESUNλ = Mean atmospheric solar irradiance [w/ (m2 μm)].

θs = Solar zenith angle (°)

$$LST = \frac{T_B}{\ln \epsilon} * (T_B/\rho + \lambda\ ) + 1$$

where;

λ is the wavelength of the emitted radiance which is equal to 11.5μm. ρ h.c/σ, σ Stefan Boltzmann's constant which is equal to 5.67 x 10-8 Wm-2 K -4, h Plank's constant (6.626 x 10 -34 J Sec), c = velocity of light (2.998 x 108 m/sec) and ε is the spectral emissivity.

3. RESULTS

Satellite image analysis of Landsat 2009 image (Figure **3**) showed that in exception of locations such as Atonsu, Suame and Kotei that have high temperature values most of the metropolis experienced moderate to low Land Surface Temperature (LTS) values. For example, areas around south of Deduako and Mampong had low temperature values.

The 2015 Landsat image map showed rise in temperature that covered wide areas of the city compared to the 2009 image. Places around Suame, Kwadaso and Tafo were places that had increased temperature while moderate temperature occurred around Agriculture College, Boadi and Anwumanso. Places of low land surface temperature occurred at the

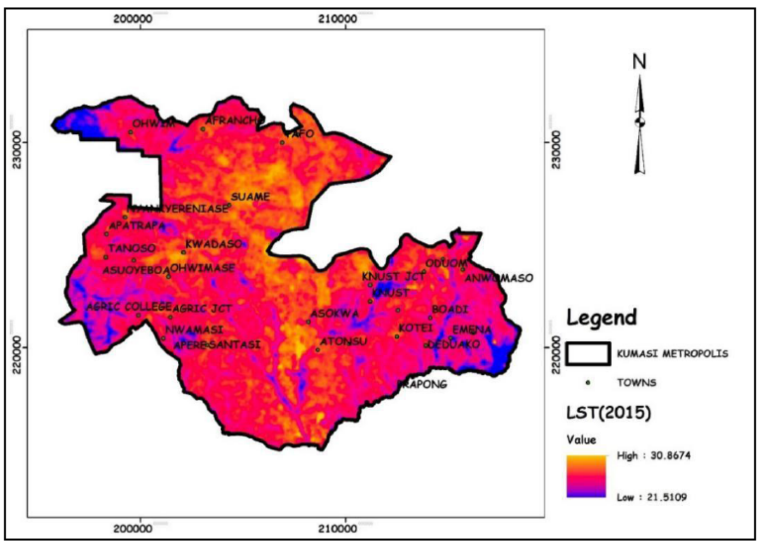

Figure 4: Land Surface Temperature Map (2015).

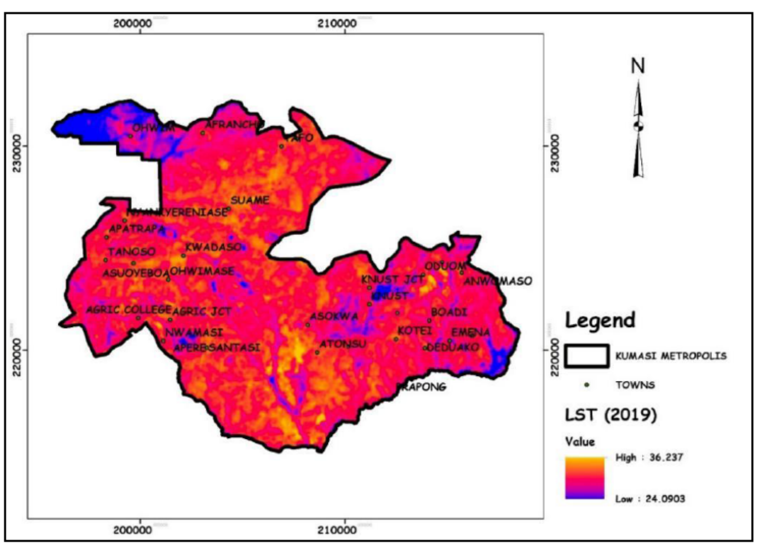

Figure 5: Land Surface Temperature Map 2019.

western part of Ohwia, Agriculture College, KNUST and Emena.

Landsat 2019 image result showed a further spread of high Land Surface Temperature to places such as Suame and Atonsu by a very small margin (Figure 5). A greater part of the southern part of Deduako and Prampong changed from low land surface temperature to moderate temperature while much of the low temperature shifted to the west of Ohwimase.

Over a period of 10 years (Figure **6**) the Land surface temperature of the Metropolis showed a steep rise in temperature from 2009 to 2015 and then slightly increased from 2015 to 2019. The trend of Land Surface Temperature change can best be described as a linear increase (red line) in 10-years. The effect of the sun on the human body from mid-day to 4.00pm can be scorchy at places of high temperature locations and mild temperature experienced at homes where the temperature is moderate on the map.

3.1. Vegetation Health Analysis

Analysis of Normalized Difference Vegetation Index (NDVI) for the 2009 image is meant to explain the extent of greenness of vegetation and crop areas within the metropolis to determine whether there is any relationship between land surface temperature and vegetation to the extent of vegetation having an influence on temperature. Vegetation condition has been mapped as high, moderate and low NDVI values in a rage of 0.0146 to 0.6914. As a rule, NDVI values of 1 or near 1 represent healthy green vegetation cover while lesser values show low green vegetation concentration. In this regard, the NDVI values of 0.6914 covering Ohwimase and Emena showed high vegetation presence whereas Suame through Kwadaso

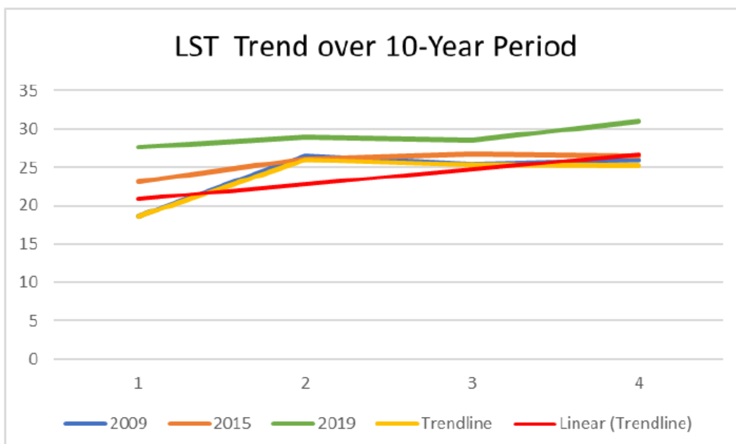

Figure 6: Land Surface Temperature Trend over 10-years.

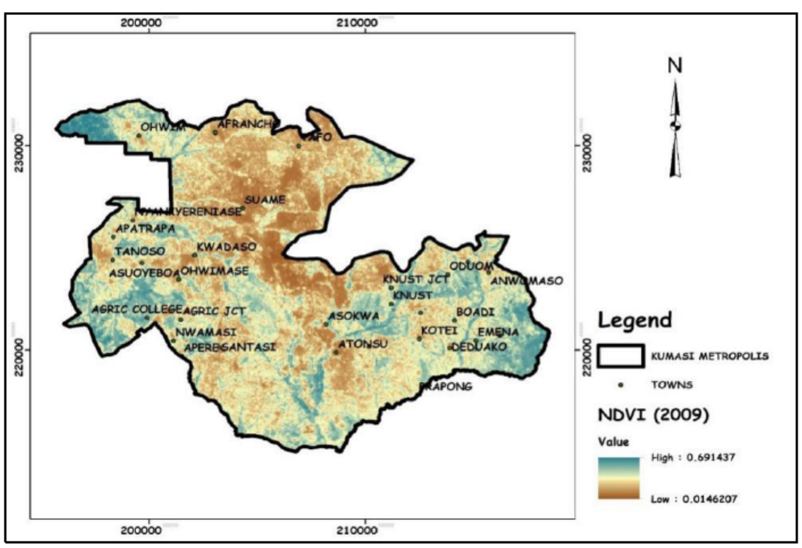

Figure 7: Normalized Difference Vegetation Index Map 2009.

to Atonsu had less vegetation given the lower NDVI value of 0,0146.

Areas of vegetation concentration in the 2015 NDVI map showed high NDVI value of 0.3557 which decreased to moderate green vegetation and later absence of vegetation at a value of 0.0437 due to clearing of the vegetation to build houses, commercial centres and industries (Figure **8**). Areas of High NDVI values can be found at the Agricultural College, KNUST and west of Ohwimase which were earlier identified in the Land Surface temperature images as low temperature areas. Moderate temperatures exist at south of Kotei, and Asuoyeboa areas. The Low NDVI areas are located around Suame and Atonsu areas which were earlier identified as high temperature areas. Comparison of the image results with meteorological data showed the annual temperature recorded for 2015 was in the range of 21.5℃ and 30.8℃ showing a sharp rise in temperature from 2009 to 2015.

Visual analysis of the 2015 NDVI image map (Figure **8**) showed areas of high NDVI at the west of Ohwimase, and Apladi. The high NDVI areas are also places of low land surface temperature. Low NDVI index areas are wide spread over the metropolis such as Suwame, Afrancho, and Kwadaso. The decrease of vegetation in these areas is as a result of construction of houses and roads which are actions that contribute to greenhouse gas emissions.

In 2019 the extent of vegetation cover reduced further from the state it was in 2015 where the highest

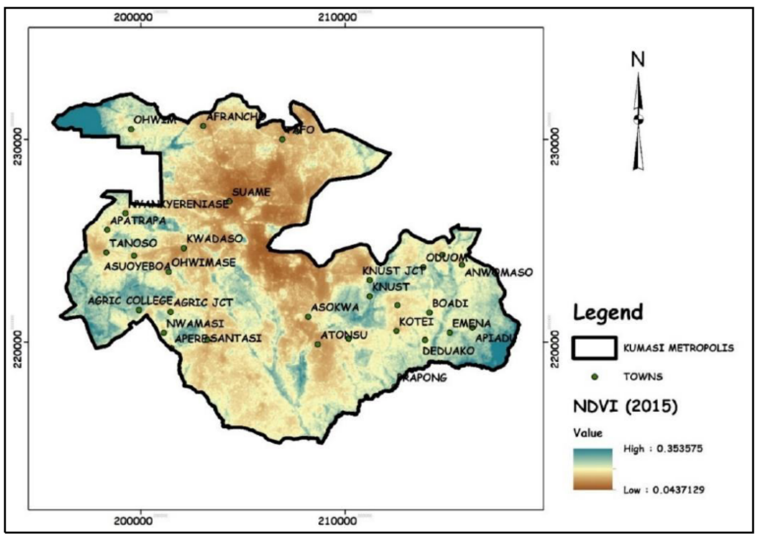

Figure 8: Normalized Difference Vegetation Index Map (2015).

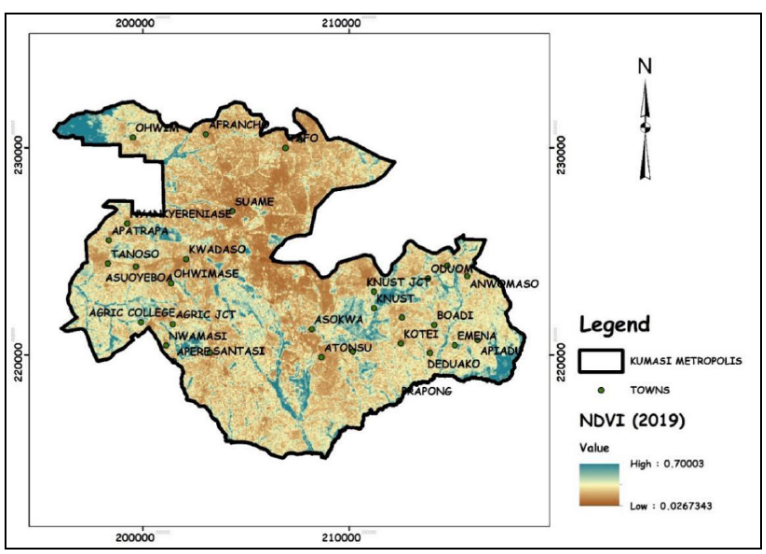

Figure 9: Normalized Difference Vegetation Index Map 2019.

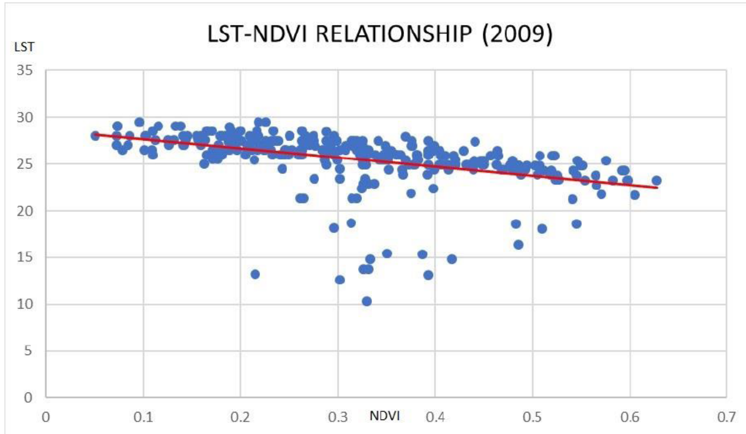

Figure 10: LST-NDVI Relationship (2009).

NDVI value was 0.7 and the lowest value was 0.0267. High NDVI locations are Apladi, KNUST and west of Ohwimase. Much of the metropolis is devoid of vegetation because of the high level of infrastructure development which is at its peak.

3.2. Correlation between Land Surface Temperature and NDVI

Correlation analysis helps to establish the level of relationship between two variables and also explain the effect of one variable on the other. In this study the correlation analysis has helped to explain the relationship between land surface temperature and vegetation presence in terms of places of high temperature having low vegetation cover and low temperature areas having high vegetation cover.

The scatter plot for 2009 showed a negative correlation between temperature and NDVI as areas of high Land Surface Temperature have low vegetation cover while low Land Surface Temperature areas had more green vegetation cover. For this reason the plotted values showed that as temperature decreases from over 25°C to about 24°C the NDVI values increased from 0.1 to 0.6. The relationship showed that parts of the city where there is concentration of concrete infrastructure have high levels of land surface temperature but low in NDVI which is a negative correlation.

Figure **11** showed a similar negative relationship where temperature is seen to be decreasing from close to 29°C to about 24°C in 2015 while areas of healthy green vegetation increased from 0.05 to 0.25 NDVI values. Statistics from the meteorological department for 2015 was a moderate temperature values of 24.1℃ and a high temperature value of 36.2 ℃ that is not much different from the satellite image calculations. These positive NDVI values showed the presence of vegetation but the spread of vegetation over the metropolis in not heavy as the values are not close to 1

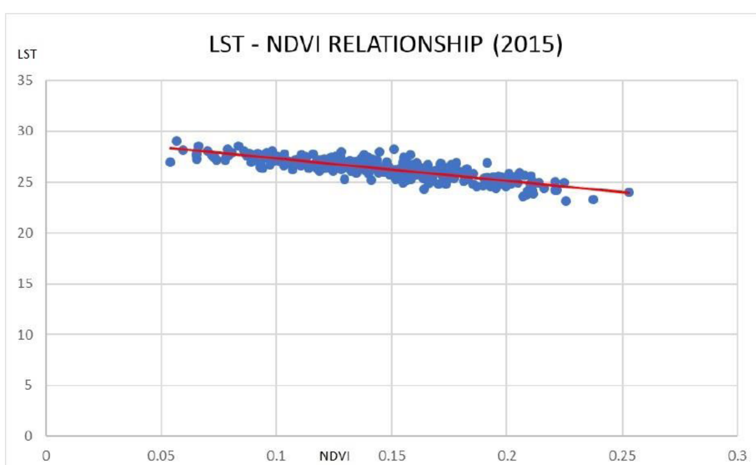

Figure 11: LST-NDVI Relationship (2015).

which is considered the maximum NDVI value. This kind of result exist because of the massive infrastructure development that has changed the status of the city from a garden city in the 1970 and 1980s when the city looked like a forest in satellite images to its present state of massive concrete infrastructure.

The correlation in 2019 showed Land Surface Temperature exceeded 30°C at its peak and decreased to about 28°C in course of the year an indication of an annual decrease in temperature by 2°C. This decrease explains the near linear negative relationship between Land Surface Temperature and Vegetation. It can be seen from Figure **12** that the NDVI values lie in the range of 0.1 to 0.6 an indication of low to moderate vegetation cover in the metropolis, certainly not a city with dense tree cover.

4. DISCUSSIONS

The Land Surface Temperature for 2009 showed areas with high Land Surface Temperature such as Suame and Atonsu. Other parts of the metropolis showed moderate temperature while few places showed low temperatures. The temperature map for 2015 showed increase in temperature from 2009 to 2015 giving rise to the spatial spread of high surface temperature areas. There is also evidence that places of low temperature in the metropolis have spatially expanded. From 2015 to 2019 there had been an increase in temperature by a margin of 2 ºC. In terms of the trend of increase in Land Surface Temperature it can be described as near linear in 10 years. Satellite image analysis of urbanization in Kumasi showed loss of the vegetation cover to built up/bare land and concrete surfaces due to expansion of the city which resulted in a surface reflectance of temperature ranging between a minimum of 24ºC (297K) to a maximum of 53ºC (326K) from 2002 to 2008 (Appiah, Forkuor, & Bugri, 2017). Also, air temperature data for 2009 showed low to moderate temperature values of between 7.93ºC and 33.84ºC implying that the Land Surface Temperature was not very high due to the presence of trees in parts of the metropolis.

Normalized Difference Vegetation Index analysis for the 2009 image showed NDVI values of 0.0146 to 06914 an indication of low to moderate NDVI values. In 2015 the NDVI values showed decline in vegetation extent given the NDVI values of 0.0437 to 0.3557. In 2019 however, the extent of vegetation seemed to have increased given the NDVI value of 0.0267 to 0.7. High NDVI values more than 0.3 indicate rich and healthy vegetation and NDVI values below 0 indicate water body and from 0.01 to 0.02 showed no vegetation exist (Sahana, Ahmed, & Sajjad, 2016).

The correlation between Land Surface Temperature and NDVI showed a negative linear relationship where areas of high Land Surface Temperatures are places with decreased NDVI values. In the Kaduna metropolis in Nigeria estimation of land surface temperature using Landsat ETM+ images of 2001, 2006, 2009 and OLI 2015 showed NDVI had negative correlation with LST (Ilayaraja, Reza, Kumar, Paul, & Chowdhary, 2016). Alemu, (2019) observed that maximum NDVI values decreased over time in 1986, 2000 and 2016 while the surface temperature of land increased by 0.081°C per year indicating a negative correlation in Andasa watershed in Ethiopia. Similar results exist elsewhere such as (Running *et al*. 1995; Tucker *et al*., 2001; Kustas *et al*., 2003; Anderson *et al*., 2004; Karnieli *et al*., 2006; Agam *et al*., 2007a.

5. CONCLUSION

From 2009 to 2019 there was increase in temperature showing a negative correlation between

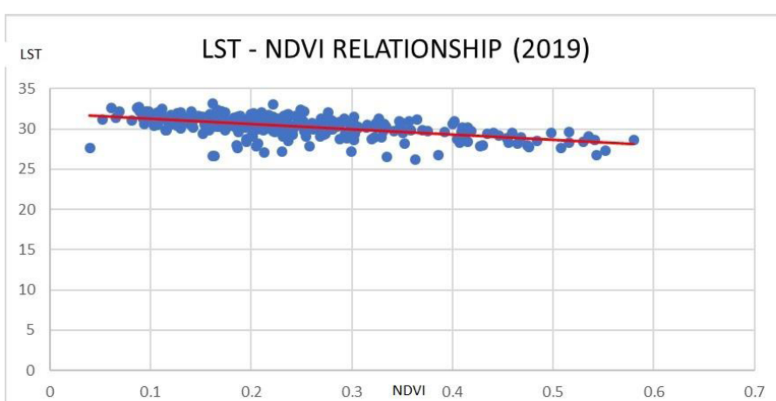

Figure 12: LST –NDVI 2019 Relationship.

Land Surface Temperature and NDVI. This result explains why parts of the Kumasi metropolis is experiencing high temperatures while moderate to cool or low temperature is felt in other parts of the metropolis. The rising city temperature can be attributed to the black body effect of buildings, roads, factories and commercial centres that are ever expanding. Planting of more trees can stem the urban heat island situation for the city to regain its original garden city status.

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