URBAN GROWTH AND LAND SURFACE TEMPERATURE DYNAMICS

URBAN GROWTH AND LAND SURFACE TEMPERATURE DYNAMICS: LESSONS FROM GHANA

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Abstract
The rapid urbanization taken place in Africa and its accompanying urban expansion is having several environmental ramifications that need urgent attention to achieve sustainable urban development. This study assessed the spatial and temporal extent of urban expansion and resultant land surface temperature (LST) changes in the Awutu Senya East Municipal, Ghana. Landsat 7 satellite images between 1991 and 2018 were classified into four categories: Built-Up, Vegetation, Barren Land and Water. The LST and Normalized Difference Built-up Index (NDBI) values were extracted from the satellite images and analyzed. Results of the study showed significant increase in Built-Up areas within the study period and also demonstrated a positive correlation between the expansion of constructed areas and increases in LST and NDBI values. Rapid urbanization was found to account for the loss in vegetation cover in the study area leading to increased LST and NDBI values. The study therefore recommends tree planting by residents of Awutu Senya, the enforcement of regulations on the choice of building materials, as well as provision of an effective transport system to aid the minimization of the observed high LST values.
Keywords: Urban Growth, Land Surface Temperature, Remote Sensing, Awutu Senya Municipality, Ghana

1. INTRODUCTION

The rapid growth of the world's population has sparked unprecedented urbanization, inducing urban growth in countries across the world over the last century. Available statistics show that in 1800, only about 3% of the world's population lived in cities. However, in 1980, whiles 4.4 billion people were living on earth, 1.7 billion people, thus 39% of the world population lived in cities. By 2015, this number had

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increased to 3.9 billion accounting for 54% of the 7.3 billion world population (UN, 2019). According to projections by United Nations, the urban share of the world population will grow to 6.4 billion, thus 66% of the 9.7 billion projected world population by 2050 (UN Habitat, 2020). Tarawally et al. (2018) indicated that there has been global astronomical increase in the number of urban dwellers, with a simultaneous increase in economic activities.

Further studies have indicated that increasing human concentration and activities tend to make urban areas warmer than undisturbed surroundings such as the peri-urban and rural areas due to urban expansion; a situation which has now become known as Urban Heat Island (UHI) (Zhou et al., 2011). According to Laosuwan et al. (2017), urban areas have developed as a result of economic growth, leading to the replacement of hitherto agricultural and vacant lands by public infrastructures such as buildings, streets and many other concrete surfaces. These infrastructure containing concrete and asphalt, contribute to increasing solar heat absorption in urban areas, allowing for higher temperatures in urban areas compared to surrounding rural areas. The Intergovernmental Panel on Climate Change (IPCC) stressed that, land cover changes have the potential to raise ambient temperatures of urbanized areas by 4°C by 2100 (IPCC, 2018). Urban Heat Islands have maximized the number of heat wave days and tropical-like night conditions in several temperate cities, including Paris, Baltimore, Washington D.C, and Shanghai, during the summer (Tarawally et al., 2018).

In Ghana, land use and land cover patterns have undergone fundamental changes due to polarized accelerated economic development since independence (Ampim et al., 2021; Mensah et al., 2019; Acheampong et al., 2018; Braimoh & Vlek, 2003), especially in the coastal area which contain three major regions of Ghana (Greater Accra, Central and Western Regions). Ghana has moved from a more dominant rural population to an urban one with more than half (50.9%) of its population living in urban areas since 2010 (Ghana Statistical Service, 2014). The 2021 National Population and Housing Census of Ghana indicated that presently 56.7 percent of Ghana's total population now resides in urban areas (Ghana Statistical Service, 2022). This is particularly true in the Awutu Senya East Municipality in the Central region of Ghana where massive agricultural lands have been converted to urban related uses to contain the high rate of urbanisation. The Awutu Senya East municipality has witnessed an unparalleled urban expansion with 94.1% of its resident population living in urban areas, and 5.9% living in the rural areas (GSS, 2014). This among other things is due to its proximity to the sprawling Greater Accra Metropolitan Area (GAMA) which serves as the capital city of Ghana. Rapid urban growth creates severe environmental consequences, including absence of nature in the city, urban ecosystem transformation and heat wave among others (Ampim et al., 2021; Weng, 2001). The forgoing together with future urban population projections which indicate steady urbanization in the next three decades with intense pressure on urban natural environment therefore makes it critical to assess the environmental impact of the rapid urban growth and proffer solutions to achieve sustainable urban development. It is in view of this that this paper seeks to use the integrated method of remote sensing and GIS techniques to assess the spatial and temporal extent of urban expansion and resultant land surface temperature changes in the Awutu Senya East Municipal, Central region, Ghana.

The paper makes significant contributions to both local and international discourse on urban development. Locally, the paper gives insight on the realities of urbanization and its impacts on the natural environment to inform the revision of the first (2012) National Urban Policy of Ghana which is still in force. Furthermore, it provides useful policy direction towards the realization of the 40-year development plan of Ghana especially the third objective of the plan which focuses on building safe, well planned and sustainable communities. In the international realm, the paper contributes ideas to enhance the achievement of African Union (AU) Agenda 2063 especially goal 7 of the first aspiration which deals with achieving environmentally sustainable and climate resilient economies and communities by 2063 (African Union, 2015).

2. MATERIALS AND METHODS

2. 1 Study Area

The Awutu Senya East Municipal is located in the eastern part of the Central region, within latitudes 5º45' south and 6º00 north, and from longitude 0º20 west to 0º35 east. It shares common boundaries with Ga South Municipal Assembly (in the Greater Accra Region) in the east, to the north with the mother district Awutu Senya district, and Gomoa East district in the west and south (GSS, 2014; Aboagye, 2014). The municipality covers a total land area of about 108.00sq.km, about 1.1 percent of the total land area of the Central region. Kasoa, the municipal capital, is located at the south eastern part, about 31kilometers from the national capital, Accra (Figure 1). According to the GSS Analytical Report in 2014, the municipal forms part of the south-west plains of Ghana and is one of the hottest parts of the country; temperatures are high throughout the year, and range between 23ºC-33ºC, with February recording the highest temperature annually (GSS, 2014). The report further showed that the average rainfall of the municipality is about 750mm, heavier during the major seasons between March and September.

The topography of the municipal is characterized by isolated undulating highlands located around Ofaakor and Akweley area. The nature of the topography is directly related to the soil type. The highland and lowland areas have loamy soils and clay soils respectively. The drainage in the high areas are not intensive as compared to the lowland areas. Okrudu, the major river in the municipality, drains from the north western part into the sea in the south, mostly causing flooding during the rainy season (GSS, 2014).

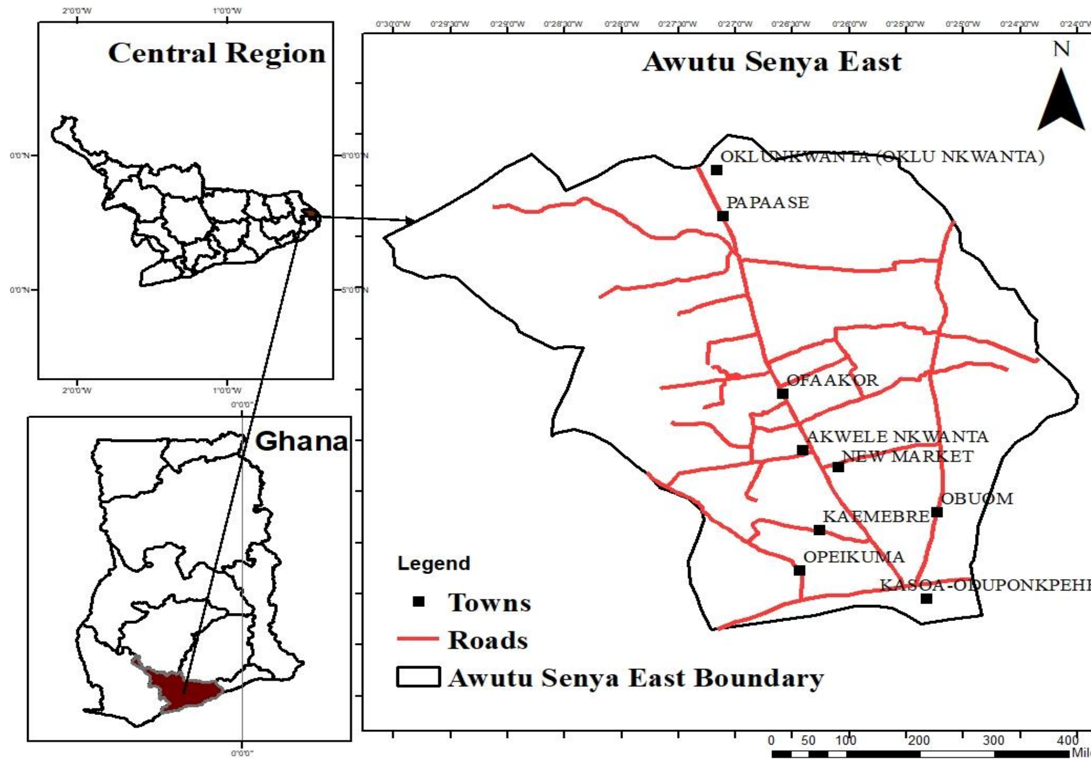

FIGURE 1 - MAP OF GHANA SHOWING THE STUDY AREA
Source: Fieldwork (2020)

2.2 Methods

The study used Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) images with a 30m spatial resolution acquired in the years; 1991, 2003, 2008 and 2018. Also, secondary data and materials such as Ghana districts shapefile were downloaded from rsgis.ug.edu.gh online portal in order to extract the district boundary of the study area (Awutu Senya East).

The Environment for Visualizing Images (ENVI) 5.0 and ArcGIS 10.5 software were used for achieving the objectives of the study. The ENVI 5.0 software was used to perform image pre-processing and processing, as well as land cover classification of each satellite image for analysis. The ArcGIS 10.5 software was used to generate the temporal surface temperature values of each satellite image, the Normalized Difference Built-up Index (NDBI) values and also a map of the study area. Microsoft Excel was also used to generate correlation graphs for analysis.

2.3 Data processing

Using the ENVI 5.0 software, 3 Landsat 7 ETM (2003, 2008, and 2018) images were corrected for the SLC-off using the extension tool in the ENVI software called Landsat gapfill. Afterwards, radiometric correction (calibration) of the bands 3(red), 2(green), and 1(blue) of each Landsat image was performed. The bands (3, 2 and 1) of each image were geometrically corrected (Layer stacking). The band combination (3, 2, 1), which is the natural colour combination, enhances visibility in urban studies. The thermal band (band 6) of each satellite image was radiometrically calibrated and used to calculate land surface temperature using the ArcGIS 10.5 software. The NDBI values were then extracted using bands 5 and 4 of each satellite image in ArcGIS.

2.4 Data Analysis

Four land cover types were used; (1) Built-up, (2) Barren land, (3) Water, and (4) Vegetation. The Built-up class includes buildings, roads and other human establishments; Barren land include exposed or cleared fields; Water include all waterbodies, and Vegetation include forest, grassland, farmlands and any other plant cover. With the aid of the ENVI software, each geometrically corrected Landsat image was enhanced using histogram equalization (in order to gain a higher contrast) to increase the volume of visible information for analysis. A supervised classification with the maximum likelihood algorithm was conducted to classify the geometrically corrected Landsat images, using the identified land cover types (built-up, barren land, water, vegetation) as training sites. Maximum likelihood algorithm was preferred because it has more accurate results given the nature of the study area (Diallo et al., 2009). Change detection algorithm was then used to detect changes in land use and land cover from 1991 to 2018 in the study area.

The NDBI technique was utilized for further analysis. This algorithm was used to extract the built-up areas automatically from satellite imagery; it highlighted urban areas where there is typically a higher reflectance in the Shortwave-infrared (SWIR) region, compared to the Near-infrared (NIR) region (Mahboob et al. 2015). Since the study concentrates on the mapping of urban or built-up areas, all the mapped land covers were categorized into only two groups, built-up and all others. The equation for NDBI is given as: $\frac{\mathrm{SWIR}-\mathrm{NIR}}{\mathrm{SWIR}+\mathrm{NIR}}$.

The land surface temperature of the Landsat images was identified in ArcGIS 10.5. The thermal infrared data (band 6) were used to generate the land surface temperature for each satellite image through the following steps; (I) conversion of Digital Numbers (DN) to spectral radiance; (ii) conversion of spectral radiance to brightness temperature; and (iii) conversion of brightness temperature to Land surface temperature. A field validation was conducted in order to access the accuracy of the analyses relative to the actual situation on the ground. In doing this, first of all, Google Earth (pro) was used to assess the study area before and after the classification analysis in order to accurately classify the area with regard to what is on the ground. Also, a field trip was embarked on to the study area, where coordinates of some areas were picked and used to identify how the classification and the NDBI analysis correlate with the situation on the field. The above GIS and remote sensing analysis were supplemented with primary data

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in the form of a questionnaire. In all, 60 questionnaires were administered to residents of the study area who were selected through cluster sampling with 20 respondents each selected from the north, middle and south zones of the study area.

3. RESULTS AND DISCUSSION

3.1 Urban growth and land cover change in Awutu Senya East

Land cover change analysis from the Landsat data for the periods 1991, 2003, 2008 and 2018 show that Awutu Senya East has gone through diverse changes and a dramatic urban expansion over the last three decades. Results from the classification show that built-up area has increased by about 50.76km² (87.74%), with vegetation cover decreasing by about 32.32km² (55.87%) over the past 27 years (Figure 2 and Table 1).

TABLE 1 - A DISPLAY OF AREA OF LAND COVER CLASSES IN 1991, 2003, 2008 AND 2018

CATEGORIES	1991		2003		2008		2018		CHANGE(2018-1991)	
	AREA(KM²)	AREA (%)	AREA(KM²)	AREA (%)	AREA(KM²)	AREA (%)	AREA(KM²)	AREA (%)	AREA(KM²)	AREA (%)
BARELAND	19	32.84	37.76	65.27	26.36	45.57	0.49	0.85	-18.51	-31.99
BUILT-UP	3.29	5.69	11.39	19.69	27.42	47.39	54.05	93.43	50.76	87.74
VEGETATION	34.08	58.91	8.51	14.71	2.87	4.96	1.76	3.04	-32.32	-55.87
WATER	1.48	2.56	0.19	0.33	1.2	2.07	1.54	2.66	0.06	0.10
TOTAL	57.85	100	57.85	100	57.85	100	57.85	100		

Source: Data analysis (2020)

This dramatic change stems from the increase in the movement of people into the municipality over the years, leading to the clearing of vegetation covers for residential, commercial and social activities. According to GSS (2014), Awutu Senya has experienced an unprecedented population growth of more than 17% per annum which qualifies the area as the fastest growing urban settlement in Ghana. Additionally, the municipality has also witnessed rapid residential development as a result of relocation of families from both inner city (Accra) and surrounding communities. It is estimated that about five hundred families move into the municipality quarterly (Acheampong, 2015). These statistics were confirmed by the results from the field which indicated that, out of the 60 respondents, 92% were migrants and only 8% hailed from the municipality.

In addition, the classification maps for the periods 1991, 2003, 2008 and 2018, show the spatial extent of land cover change in the municipality over the last 27 years. The urban area in 1991 was dominant in the southern part of the study area, along the Accra-Cape Coast highway; in areas such as Old market, Zongo, High tension, and Obuom; with smaller portions in the north central parts in towns like Kwao Bondze and Ofaakor. From 2003 through to 2018, the urban area gradually spread widely northwards along the Bawjiase, Opeikuma, New market, and Obuom, specifically in towns such as Kaemebre, Akweley, Ofaakor, Papaase and near the Jei River. Whilst the urban areas significantly increased, the vegetation cover in the study area gradually decreased; with the dominant vegetation cover now concentrated in the north western tip of the study area, where urban expansion is very minimal due to lack of social amenities (roads, water, electricity etc.) since it is a new developing area.

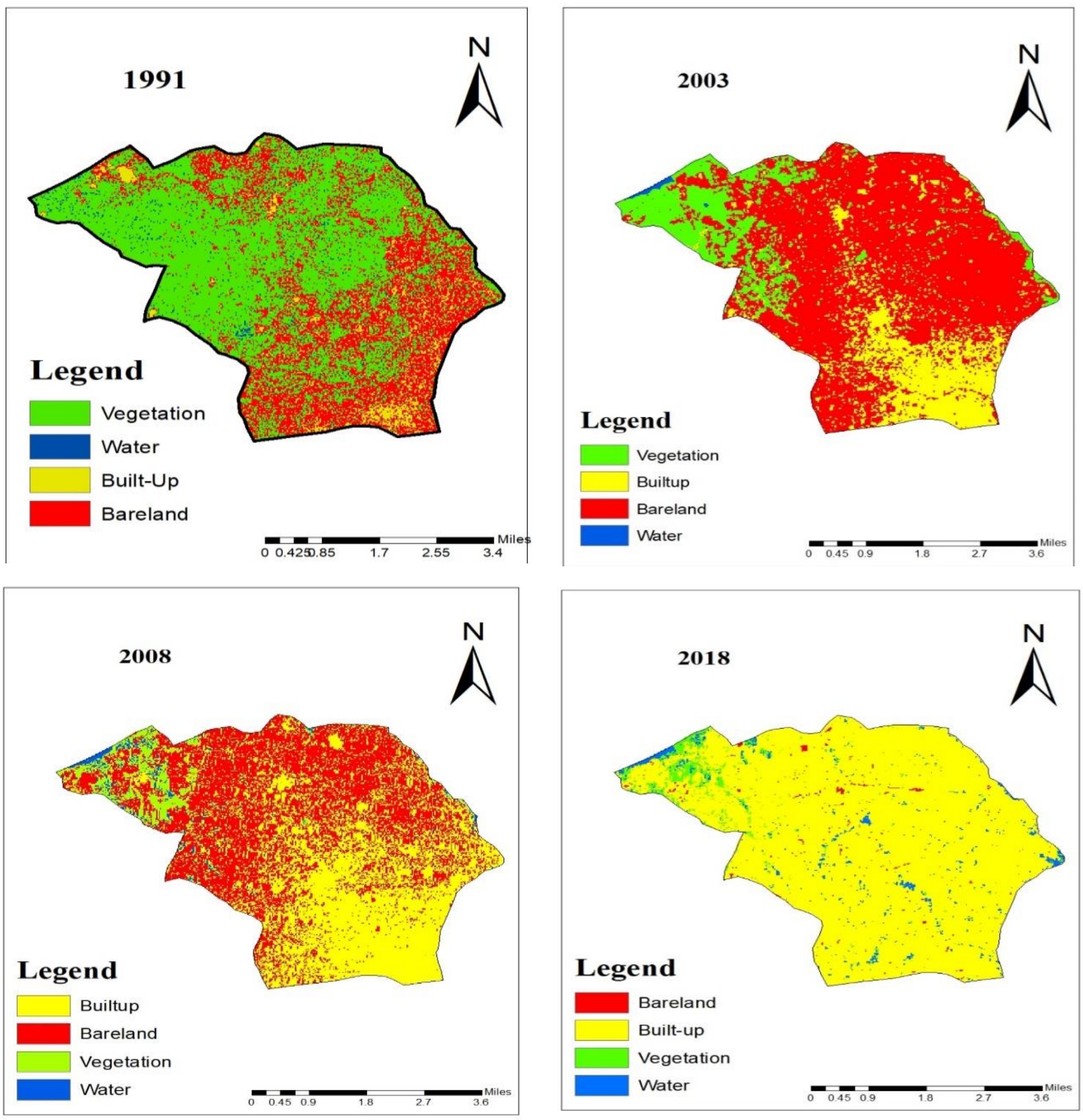

FIGURE 2 - CLASSIFIED MAPS OF AWUTU SENYA EAST
Source: Data analysis (2020)

Awutu Senya East which only had a population of 863 people in 1970, experienced rapid population growth to 34,719 in 2000; 108,422 in 2010; and 127,689 in 2018 (Yankson & Bertrand, 2012; GSS, 2010). According to Yankson and Bertrand (2012), Awutu Senya East is experiencing this urban explosion because Kasoa, the capital of the municipality, acts as a dormitory town for Accra, as Accra residents migrate to the suburbs mainly due to fiscal and social problems of the central city such as high taxes, high rent and congestion. Additionally, more people migrated into the municipality due to the massive infrastructural developments such as the reconstruction of the Accra-Cape Coast and Bawjiase roads, the Mallam interchange, the Kasoa interchange, and increased access to water within the municipality and its surroundings; with the dramatic expansion mostly occurring between 2001 and 2008 (35%) and also between 2009 and 2016 (48%). Also, the central part of the study area has experienced maximum urban growth and land cover change compared to the other parts of the study area. The above findings for urban expansion in Awutu Senya municipal Assembly were found not to be different from the general factors causing urban expansion elsewhere in the world as indicated by Shahmohamadi et al. (2010). Additionally, Urban Heat Island had a major negative impact on urban expansion in the study area.

3.2 Urban expansion and land surface temperature in Awutu Senya East Municipality

According to Xian and Crane (2005), rapid urban growth alters the physical properties of urban land surface, causing higher land surface temperatures in urban areas. Land surface temperature and atmospheric temperatures rise by various anthropogenic activities like increasing land surface coverage by artificial materials, and high energy consumption (waste heat), which have high heat capacity and conductivity (Ramachandra et al., 2012). Most of these impervious surfaces have very low albedo meaning that their ability to reflect heat and light back to the atmosphere is minimal due to the nature of their composition. Hence, these surfaces tend to absorb and retain heat, resulting in higher temperatures in the surrounding environment. However, other external factors can also influence the temperature or heat of surrounding environment.

The dramatic urban expansion in Awutu Senya East involve the construction of infrastructures such as roads, houses, sidewalks, markets, amenities etc. which are all made up of impervious materials such as asphalt, concrete, bricks, stone and rooftops, that trap heat. From the temperature maps for the periods (1991, 2003, 2008 and 2018), a minimum and a maximum temperature range of 21°C - 24°C and 27°C - 36°C were recorded respectively. High surface temperatures (27.3°C in 1991; 32.6°C in 2003; 35.5°C in 2008; and 30.3°C in 2018) were observed in areas such as Old Market, Zongo, Opeikuma, Kaemebre, Obuom, New Market, and Ofaakor with their extent increasing with time as the areas expanded (Figure 3 and Table 2). These areas have huge number of settlements within the municipality.

TABLE 2 - A DISPLAY OF LAND SURFACE TEMPERATURE VALUES (°C) IN AWUTU SENYA EAST

	LOW	HIGH
1991	22.835	27.3683
2003	22.841	32.657
2008	24.36	35.4616
2018	21.816	30.2733

Source: Data Analysis (2020)

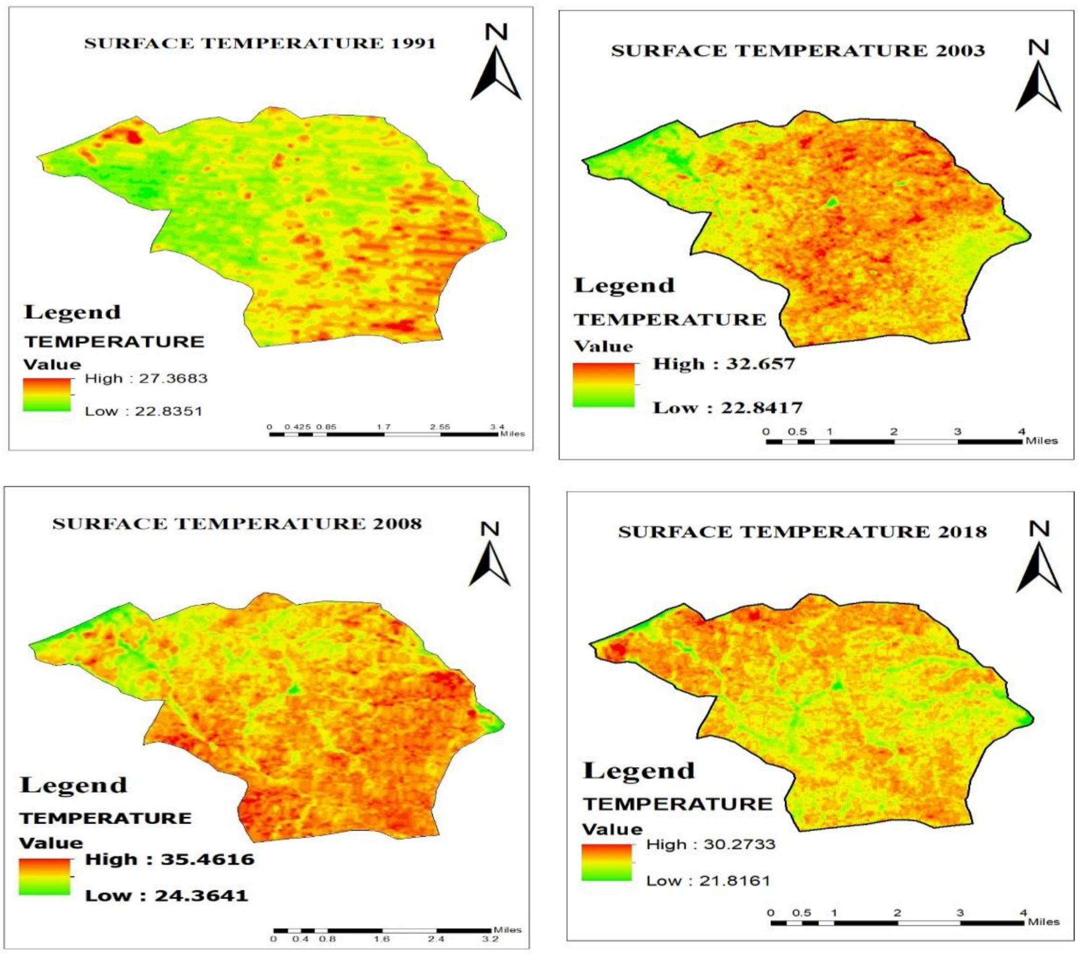

FIGURE 3 - LAND SURFACE TEMPERATURE MAPS OF AWUTU SENYA EAST
Source: Data analysis (2020)

The warming in these areas can be explained by increased anthropogenic activities supported by an increasing population size over the years within the municipality. Since Kasoa is a dormitory town for Accra (Yankson & Bertrand, 2012), many people have relocated to the municipality and commute to work and for other economic activities in Accra on a daily basis resulting in the operation of lots of public and private vehicles during the day. Due to this, areas such as Old market, Opeikuma, Obuom and New market have undergone major infrastructural development, such as the construction of the Kasoa interchange, a mini market and bus terminal in Kasoa old market, construction of a market and new market road in Kasoa new market, and the reconstruction of the Obuom and Opeikuma roads over the study period. Also, the mini market and a main market in Kasoa old market and Kasoa new market areas are the main centres within the municipality, accounting for 90% of all economic activities within the municipality. As opined by Oke (1982) who correlated heat island intensity to the size of urban population, increasing urban population in Awutu Senya resulted in increased heat island intensity. Awutu Senya has experienced dramatic influx of more people especially from Accra and its surroundings as confirmed by the field report which showed that about 94% of the residents are migrants. This buttresses the point that, the influx of more people into the municipality over the years is a major contributing factor to increase in temperature within the municipality.

The density of built-up areas within areas such as Kasoa Zongo, Old Market, Kaemebre and parts of Opeikuma and Ada-kope which are all old settlements within the municipality, was another contributing factor to increasing temperature within the municipality. Settlements in these areas are very clustered within a small space. According to Shahmohamadi et al. (2010), distances between buildings along axis, affect the solar exposure of the buildings and the potential for day lighting and for solar energy utilization for space and water heating.

It is an undisputed fact that, irrespective of these anthropogenic activities altering the spatial and temporal extent of land surface temperature within the municipal area, natural or physical factors such as the location of the study area can also alter land surface temperature within the municipal area. This best explains the fluctuations within the increasing temperature values and their spatial variations over the study period. Awutu Senya East is a low- lying area, only a border away from Gomoa East near the Atlantic Ocean, and as result, experiences the sea breeze from the ocean especially in the southern part.

Other probable factors that were found to influence the surface temperature of the study area were government and local authority intervention policies. For instance, in Awutu Senya East Municipal, the channel of the Okrudu River, a major river body stretching from the north to the south of the study area is occasionally dredged. Dredging is done as an intervention act by the local authorities to control flooding within the study area, but also increases the water coverage area as indicated by classification results (whereby water area increased from 1.2 km² to 1.54 km² in 2008 and 2018 respectively), which can lead to a reduction in surface temperature. According to anecdotal evidence, dredging the river started in 2012 which could explain the spatial and temporal variations in Land Surface Temperature (LST) within the study area, especially the reduction of LST from 35.5°C in 2008 to 30.3°C in 2018 even though Built-up area increased from 27.42 km² to 54.05 km² within the same period. Irrespective of this, the maximum temperature values obtained (thus 27°C-36°C) were very similar to the GSS estimated high temperature values (GSS, 2014) and were almost constant throughout the year ranging between 23°C-33°C.

3.3 Correlation between urban growth and surface temperature of the study area

Correlation between the LST and NDBI provides a quantitative description of spatial and temporal variation of urban thermal patterns that characterizes land-use and land-cover types (Zhang et al., 2009). The NDBI method was employed as it allows for a higher degree of accuracy and objectivity (ZHA et al., 2003). Therefore, the relationship between LST and NDBI was investigated by correlating the results for the four different time points (1991, 2003, 2008, and 2018). The results of multiple correlation as shown in figures 4 and 5 indicate that LST presents a positive correlation with NDBI for each time point. It was observed that in 2008, at an NDBI value of -0.41, LST was 24.4°C; and at an NDBI value of 0.48, LST was 35.5°C. Also, in 2018, at an NDBI value of -0.31, LST was 21.8°C; and at an NDBI value of 0.33, LST was 30.3°C.

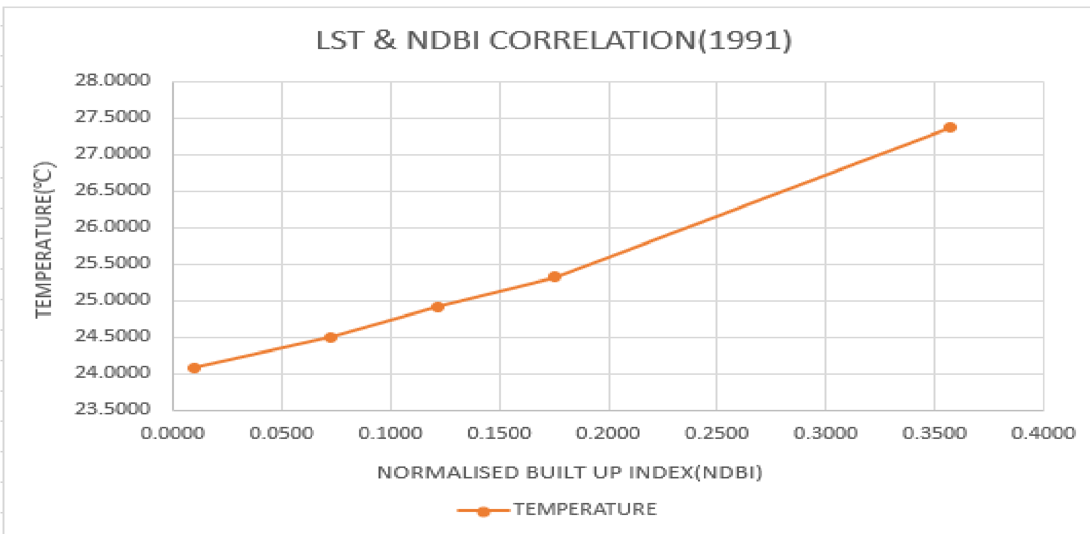

FIGURE 4A - CORRELATION BETWEEN LST AND NDBI RESULTS FOR 1991
Source: Data analysis (2020)

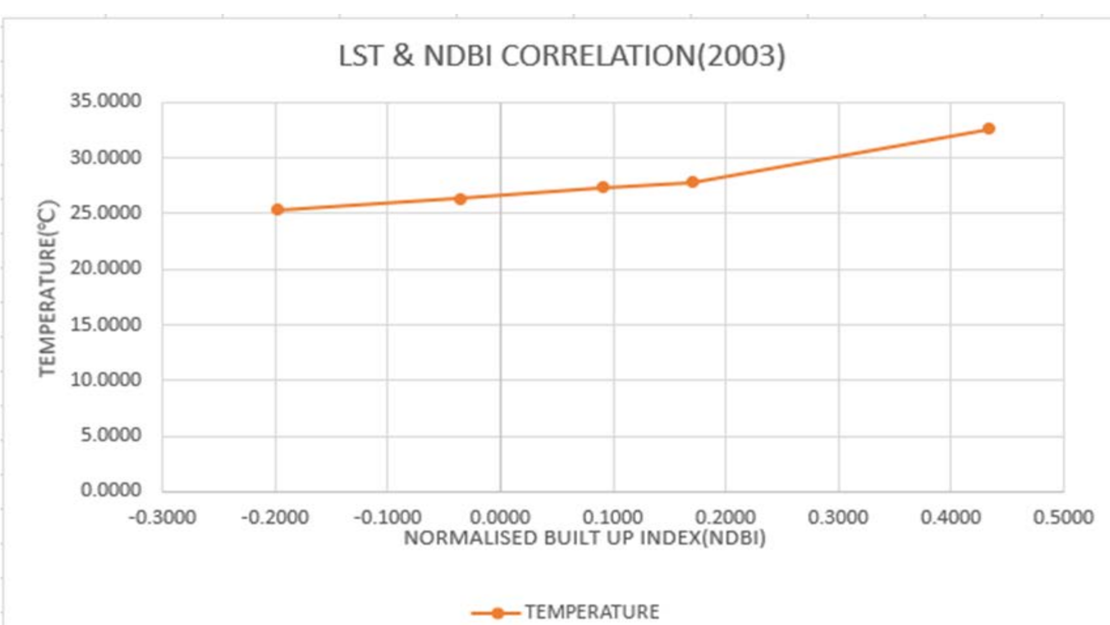

FIGURE 4B - CORRELATION BETWEEN LST AND NDBI RESULTS FOR 2003
Source: Data analysis (2020)

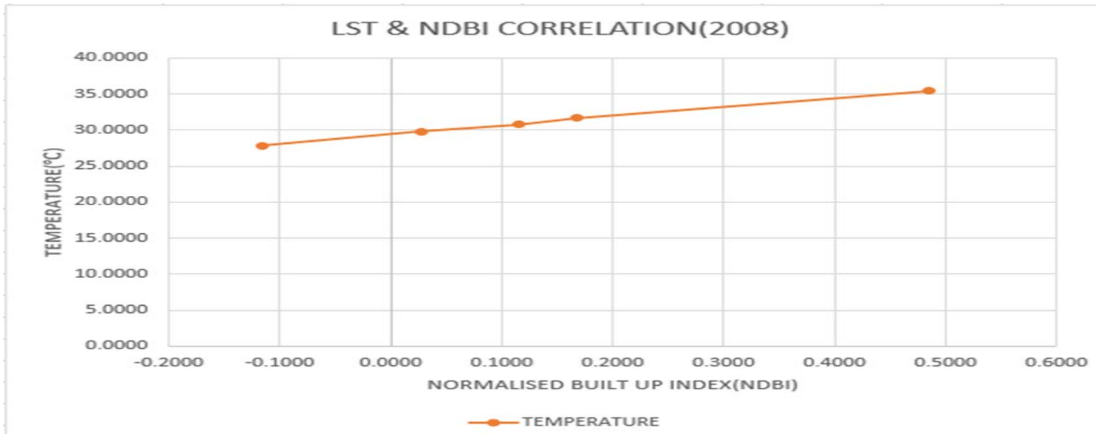

FIGURE 4C - CORRELATION BETWEEN LST AND NDBI RESULTS FOR 2008
Source: Data analysis (2020)

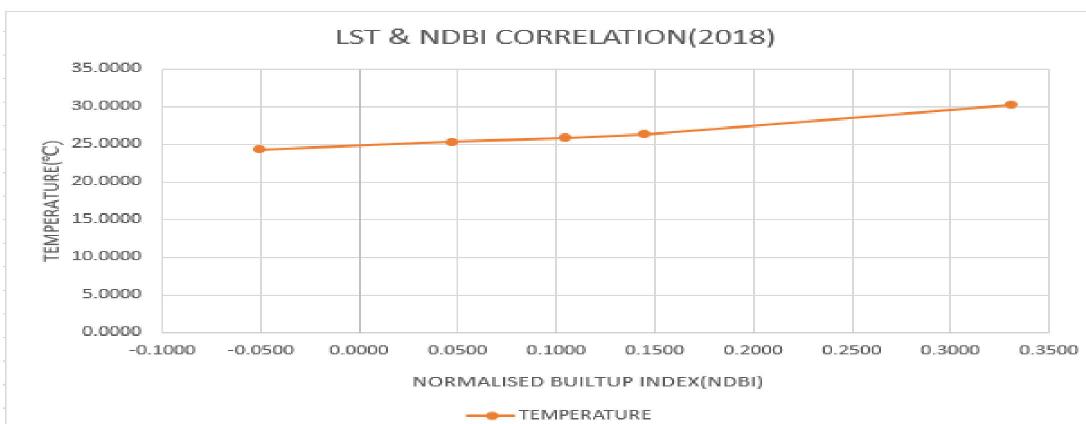

FIGURE 4D - CORRELATION BETWEEN LST AND NDBI RESULTS FOR 2018
Source: Data analysis (2020)

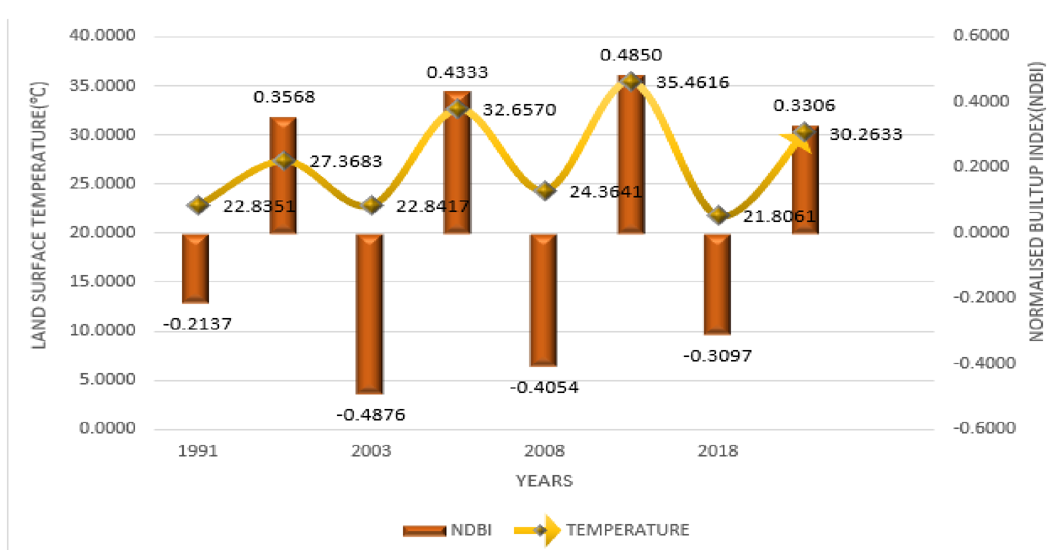

FIGURE 5 - CORRELATION BETWEEN LST AND NDBI RESULTS FOR THE ENTIRE STUDY PERIOD
Source: Data Analysis (2020)

4. CONCLUSIONS

In conclusion, this study demonstrated the usefulness of GIS and remote sensing techniques for analyzing and estimating urban growth and its corresponding effect on land surface temperature over a time period. Rapid urban growth and sprawl is a major driver of vegetation loss in Kasoa, as the study found a notable decrease in vegetation and bare land because of conversion to urban land during the span of 27 years. Surface temperature in Kasoa in Awutu Senya gradually increased, fluctuating between 27°C and 36°C during the study period. This fluctuating increase was associated with urban areas (built-up) as indicated by the positive relationship of the correlation analysis between LST and NDBI and other external factors such as the location of the study area as well as local authority policy actions. Temperature increase in the long term caused a lot of damage to the urban environment and affected inhabitants; therefore, measures have to be put in place to address this menace.

5. LESSONS FOR SUSTAINABLE URBAN DEVELOPMENT IN THE CONTEXT OF AFRICA

Looking at the above findings and situation of many urban areas in Africa which share similar problems like the study area, a number of good lessons could be drawn to build sustainable urban development in the context of Africa. First, the excessive destruction of the natural vegetation to make way for the built environment requires sustainable strategies to restore the lost vegetation cover. To achieve this, the Awutu Senya East Municipal (ASEM) Assembly and other city authorities in Africa can formulate local action plans to complement the available urban or land use policies. In the case of Ghana, this can be done to support the fourth objective of the National Urban Policy which encourages the protection of green vegetation to improve urban environmental quality. The local action plans can focus on all building plans and request for provisions of some specific percentage of green spaces in such plans before approval or permit can be given. This should apply to both new developers who are about to construct their buildings and old developers who have already settled in the area to make the necessary effort to have some desirable green spaces in their compounds. This will help to continually protect and enhance the area's vegetation cover.

Second, since the depletion of the vegetation cover was partly caused by uncontrolled and unplanned spread of residential areas, embarking on planned housing projects will be essential. In this regard, the ASEM Assembly can partner with the Ministry of Local Government, Ministry of Works and Housing, the traditional authorities and other private housing agencies to develop affordable housing schemes in some strategic parts of the study area. Such collaborations could be encouraged in urban areas of Africa. The planned nature of this housing projects will help to limit the lateral spread of houses which was found to destroy many vegetation covers in the study area. In addition, the strategic locations of these planned affordable housing projects can help regulate the nature of the population density in the area to improve surface temperatures since it will prevent heat from being trapped in high density clusters as found in the current study.

Third, the high surface temperatures coming from excessive built environment and other concrete infrastructure require strict enforcement of the provisions in the Zoning and Planning Guidelines of Ghana, the National Building Regulations of Ghana and similar planning regulations in Africa which have been found to receive poor enforcement (Mensah, 2014). With this, city engineers should have to strictly enforce that the engineering works and materials for building are environmentally friendly and are complied with by all developers. In addition, building materials such as cool roofs, coated roofs and green roofs that have high reflectance can be encouraged to be used in constructing buildings to reduce high temperatures. For instance, cool roofs such as Vinyl roofs reflect about 70% to 80% of sunlight.

Lastly, establishing an effective and efficient transport system will be a good long-term policy to minimize the high surface temperatures which were observed to be caused by expansion and over-utilization of the only road transport in the area. Since the study area is a dormitory town and many of its residents' commute on a daily basis for various economic activities, establishment of effective and efficient public transport systems such as Bus Rapid Transit (BRT) system and rail transport system which were absent in the area, can play a significant role to reduce the use of many private cars by the residents. This in effect, can help reduce carbon emission (waste heat) which were found to contribute to the increasing temperatures in the municipality.

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