Article

ASSESSING THE IMPACTS OF URBINIZATION ON THE CLIMATE OF KUMASI

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Abstract: The key anthropogenic effects on climate include the changes in land use and emission of greenhouse gases into the atmosphere. Depletion of vegetation poses serious threat that speeds the process of climate change and reduces carbon sequestration by the environment. Thus, the preservation of natural environment in urban areas is an essential component of the garden city model, proposed by Sir Ebenezer Howard in 1898, to ensure ecological balance. Recent Landsat images showed that Kumasi does not have the required percentage of green vegetation as was stipulated in the garden city model on which the city was built. It was observed that most parts of Kumasi's green vegetation have been lost to built environments. This study was conducted to assess the impact of urbanization on the garden city status and its effect on the micro-climate of the city. Significant changes in the vegetation cover of the city was evaluated from Landsat-TM imagery and analysis of a long term climatic data of Kumasi carried out over a 55-year period (1960 to 2015). It was observed that, climatic conditions have slightly changed, as mean surface temperature of has increased by $1.2°C/ 55$years, due to the significant landuse changes from development of non-transpiring, reduced evaporative urban surfaces. However, the impact is not greatly felt due to the geographical location of the city on the globe despite the evidence of a considerable temperature change. Green vegetation conservation for the city is recommended as a top priority in future for city authorities and planners.

Keywords: Landuse change, Climate change; Garden city model; Green vegetation; Landsat; Urban heat island

1. Introduction

The earth continues to undergo substantial changes due to the anthropogenic activities mostly through deforestation and urbanization. Recent development pattern of urban areas observed by the [56] found that, rapid urbanization is a critical problem with the resultant effect being destruction of much green vegetation to make way for the increasing population. Currently, roughly 80% of economic growth occurs in urban centers. According to a 2010 study from the United Nations Human Settlements Program, countries have more opportunities for economic growth through urbanization. This includes social services such as education and healthcare, reliable access to good drinking water, sanitation services, and electricity, massive industrial infrastructures and quality transportation hubs that are necessary for commercial development. Urban centers place substantially more pressure on natural resources than rural communities, given their population density and the attendant demands on water, agricultural, energy, and other resources. Recent study by [41] assessed the extent of deviation from of Kumasi from the garden city status by using archival recordds from Landsat satellite imagery. This study goes a step further to assess the impact of the urbanization on the climate of the city and the potential effect on the citizenry

The resultant expansion of urban land has significant climatic implications across all scales, since the continuous removal of natural land cover and the introduction of urban materials such as concrete, metal, etc changes the surface energy balance, resulting in an increase in sensible heat flux at the expanse of latent heat flux [48,53]. Consequently, highly evaporative surfaces have a Bowen ratio of approximately 0.1 and 1.0 for drier surfaces, due to the elevated temperatures over urban surfaces [21]. Surface characteristics such as albedo, roughness length or moisture availability control the energy balance partitioning of any surface [8]. Thus, gradually increasing the urban surface temperature

The climatic impact of urbanization has been quantified through the Urban heat island (UHI). This urban thermal environment affects residents' health, consumption and even productivity. Urban heat islands are mostly limited to a finite number of in situ temperature observations that describe the response instead of the forcing of repartitioned surface energy fluxes over urbanized surfaces [36]. Urban climate research requires good information on the land cover, which incorporates data on the urban land use changes and its associated surface energetic signature [48]. Satellite remote sensing is the most reliable and consistent way of monitoring land cover change associated with urbanization on the order of tens of kilometers. Thus, this study seeks to establish the retreat of green vegetation in Kumasi and its environs due to urbanization through analysis of spatial images from Landsat 4, 7 and 8 archives from the US Geological Survey, and further investigate its adverse effect on the climate from 1960 - 2015. The study is expected to serve as an upgrade upon earlier works by [38], who investigated the effect of global warming on Kumasi and Accra, and [17] who also investigated the impact of change in land use on the sources of drinking water in Kumasi. Change in land use within the city will affect the quality of drinking water and cause severe shortage in households if the right steps are not put in place by the city planners in this urbanization era. [45] also quantified the variability in distribution of vegetation, soil and ecosystem carbon storage in Kumasi due to recent urbanization

Mitigation and adaptation strategies are required by town planners to reduce the potential heat stress risk. Utilizing green infrastructure to lower the surface temperature, as described by [15,18,28,42]. Further studies by [60] and [20] suggested ways through which urban planners could apply innovative solutions to improve upon the ventilation potential and heat release within the urban set-up. Other mitigation practices which take into consideration land-use planning strategies at early stages of the urban planning process are needed to reduce the effect of the heat stress [31,35]

1.1. Urban Heat Island

Urbanization leads to the expansion of the cities' boundaries and the densification of the urban tissue, with construction of tall building structures along relatively narrow roads/streets. This leads to gradual destruction to the vegetational cover, which plays a major role in energy balance and water cycle of the atmosphere. However, as a result of these constructions, the heat balance within the city is altered with air temperature within the densely built area being higher than in the surrounding rural areas. This phenomenon is generally referred to as 'Urban Heat Island' [44]. Studies on the relative warm temperatures characteristic of large cities in Europe as compared with the surrounding areas had been started in the 19th century [34]. The difference between the air temperature of city characterized with UHI and its surrounding areas is large at night and small during the day. Mostly, during variably or less cloudy days, urban surfaces are warmed faster by the absorption of solar radiation.

These built surfaces within the urban cities have high heat capacities that serve as a giant heat reservoir. Concrete can roughly hold about 2,000 times as much heat as an equivalent volume of air. At night, the situation is opposite with the absence of solar heating which inhibits atmospheric convection and stabilizes the urban boundary layer. This causes an inversion layer, which traps the air near the urban surface and warms the surface air, creating warmer nighttime air temperatures within the urban city [58]. The thermal difference coupled with heat produced from fossil fuel burning of vehicles, industries and houses contribute to the Urban Heat Island effect. This study and a previous study by [38] demonstrated the rise in daily night time temperatures in Kumasi as a result of urbanization. However, these difference in temperature could be higher for other cities with respect to topographical location and other meteorological conditions. The effect of cloud cover on daytime and nighttime temperatures were not determined for the area under study since no cloud cover data was analyzed

2. Methodology

2.1. Study Area

Kumasi is the second largest city in Ghana and is the commercial, industrial and cultural capital of the Ashanti Kingdom since 1695 [40]. Kumasi is approximately 500 kilometres (300 mi) north of the Equator and 200 kilometers north of the Gulf of Guinea and strategically located in south-central Ghana and all major roads converge at the city center. The city is geographically located in the moist semi- deciduous part of the South- East ecological zone of Ghana and within the tropical rain forest belt of West Africa, with average elevation of about 853 feet above the mean sea level [3]. The city has an aggregate area of roughly 254 square kilometers (Km^2) and comprises 10 sub-metropolitan areas, namely; Manhyia, Tafo, Suame, Asokwa, Oforikrom, Asawase, Bantama, Kwadaso, Nhyiaeso and Subin [39]

Kumasi is one of the few cities in Africa that enjoyed the implementation of the garden city model from its colonial masters who were the British. Following the defeat of the Ashanti's in a war by the British merchants in 1896, the whole city was raised down and rebuilt at the same location by the British [52]. The 1945 advancement planning which was made by Maxwell Fry and Jane Drew apportioned significant spaces for greenery. They took after the garden city model which was extremely renowned around that time. Samples of such spaces in Kumasi in that period were urban parks, greenhouses, trees, forests, and green belts. Resulting improvements of the city took after comparable example with much green spaces been protected in the city's physical scene. This circumstance made the city to pick up the honor the garden city of West Africa in the 1960s [51]

2.2. The Garden City Model of Kumasi

By mid- Nineteenth century, mechanical developments together with monetary and social conditions had led to the acceleration of industrialization in Western Europe especially in Great Britain. The effect was mass movement of people into urban areas which brought lots of congestion and made these cities vulnerable to harmful conditions [12]. Sir Ebenezer Howard (1850 - 1928) in his known publication of 1898, titled 'To- Morrow: A Peaceful Path to Real Reform', explained how big cities could live harmoniously together with nature. This introduced the garden city movement. Lentchworth Garden City was the first garden city built from this concept in 1903. The greenery enclosure city model put forward by Howard in 1898 through his published work which was later updated in 1902, was to address the undesirable ways of life in urban cities, and how nature could be incorporated in town planning to produce a third magnet (garden city) that will give man trust and life [24]

With the Greenhouse city model, the urban communities designed with the wide open magnificent spaces of nature could attract individuals to live in them, whiles preserving nature [10]
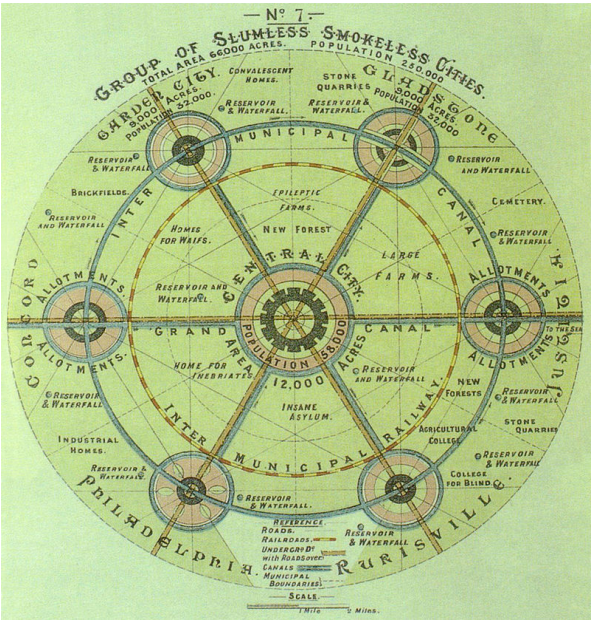

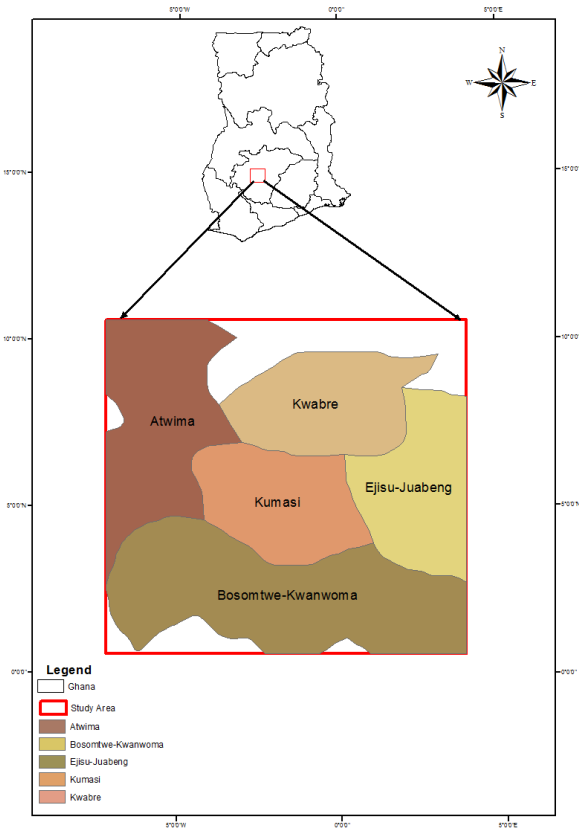**Figure 1.** The Garden city concept by Sir Ebenezer Howard: Source [26]

Figure 2. Map of Kumasi showing its surrounding towns

120 Earlier studies by [2], reveals the beautiful greenery scenery that earned Kumasi the 'Garden city of
121 West Africa'. Following the architectural designs of Maxwell Fry and Jane Drew in 1945, Kumasi had
122 an eminent green belt (330 yards wide), with waterway tributaries that transected the city through its
123 neighbourhoods including Atonsu, Kaase, Bantama and Aboabo [13]. These green spaces were
124 characterized with several parks and gardens that were used for different purposes to fulfill the
125 recreational needs of the individuals and further beautification of the city. There were five urban parks
126 situated at vantage points. These were the Kejetia Park (Adehyeman gardens), Suntreso Park (at the
127 premises of the premises of Department of Parks and Gardens), park at "Amakom" (now Kumasi
128 Children's Park), Fante Newtown Park, and Kumasi Zoological Gardens (Kumasi Zoo). The Suntreso
129 Park was known for containing a corridor passage like the English parks around then as stated by [16].
130 After these parks, it was seen that few different parks and gardens were made to serve the developing
131 population of Kumasi. The remarkable ones among them were Abbey's Park, Jackson Park, Prince of
132 Wales Park, Para Gardens and Kumasi Race Course. Others were the Kotoko Park (otherwise called
133 Cricket) behind the Manhyia Hospital; the Addo's Park behind the Manhyia Palace; the Dogo Moro
134 Park at "Asawase"; and the Rivoli Park at "Bantama" [4]. Driving or walking through the streets of
135 Kumasi which full of vegetation was a pleasure to look as one will watch a lovely view of finished
136 urban trees and gardens at the focal business region

137 *2.3. Data*

138 The spatial imageries were obtained from Landsat 4, 7 and 8 archives from the U.S Geological Survey
139 (USGS). The table 1 shows the summary of the three data sets used for the study, its source and date of
140 acquisition. These images gave simple visuals distinguishing proof and real data on the progressions
141 that have occurred in the green vegetation of the study area

Table 1. Summary of the datasets used in the analysis

Satellite	Sensor	WRS Path/Row	Date Acquisition	Spatial Resolution	Spectral Resolution	Source
Landsat 4-5	TM	195/055	20th January 1986	30m	8 bands	Earthexplorer.org
Landsat 7	TM	195/055	31st January 2007	30m	8 bands	Earthexplorer.org
Landsat 8	TM	195/055	15th January 2015	30m	11 bands	Earthexplorer.org

142   Climatic data collected from Ghana Meteorological Agency (GMet) was also used to assess the change
143   in climatic conditions over the city. GMet like any other meteorological agency under the World
144   Meteorological Organization (WMO), uses WMO's standards in its rainfall measurements. However,
145   minor inconsistencies in the measurements due to instrumental or observational error could be
146   introduced in the climate data analysis, which are quite neglegible [43]. This information accumulated
147   much data to build up a chain of confirmation about the present condition of the green vegetation of
148   Kumasi

149   *2.4. Data Analysis*

150   The Landsat imageries were analyzed using ArcGIS 10.4.1, ENVI 4.7, and MS Excel

151   2.4.1. Image Processing and Classification

152   Analysis of the land cover changes was done by processing three different satellite images
153   geometrically to its local coordinate system. The imageries were georeferenced that is, by
154   geometrically correcting the images to the local coordinate system using the Universal Transverse
155   Mercator (UTM) projection (WGS 1984 UTM Zone 30N) in ArcMap 10.4.1

156   Also before the image classification was done, the images were pre-processed. These include
157   radiometric and atmospheric corrections which are very essential in every remote sensing analysis due
158   to distortions the images contain [6]. Radiometric correction is the process to reduce the degree of
159   spectral differences emanated from the sensor leading to the images been distorted. Some of these
160   distortions include atmospheric haze, scan lines and stripping [6]

161   The Landsat 7 TM developed a faulty scan line corrector on May 2003 which led to the scan lines seen
162   in the 2007 imageries [6]. This fault was corrected and updated to Landsat 8 hence; images from the
163   period the fault was detected to 2014 have some scan lines in them. The scan lines were removed from
164   the imagery using the gap-fill extension in ENVI 4.7. Figure 5 shows the images with and without scan
165   lines. Atmospheric correction is also done to remove the atmospheric haze such as clouds caused by
166   the variations in the atmospheric conditions between the dates the images were obtained. There has
167   not been any method to completely remove the haze in the images; however, this can be minimized
168   using ENVI 4.7.
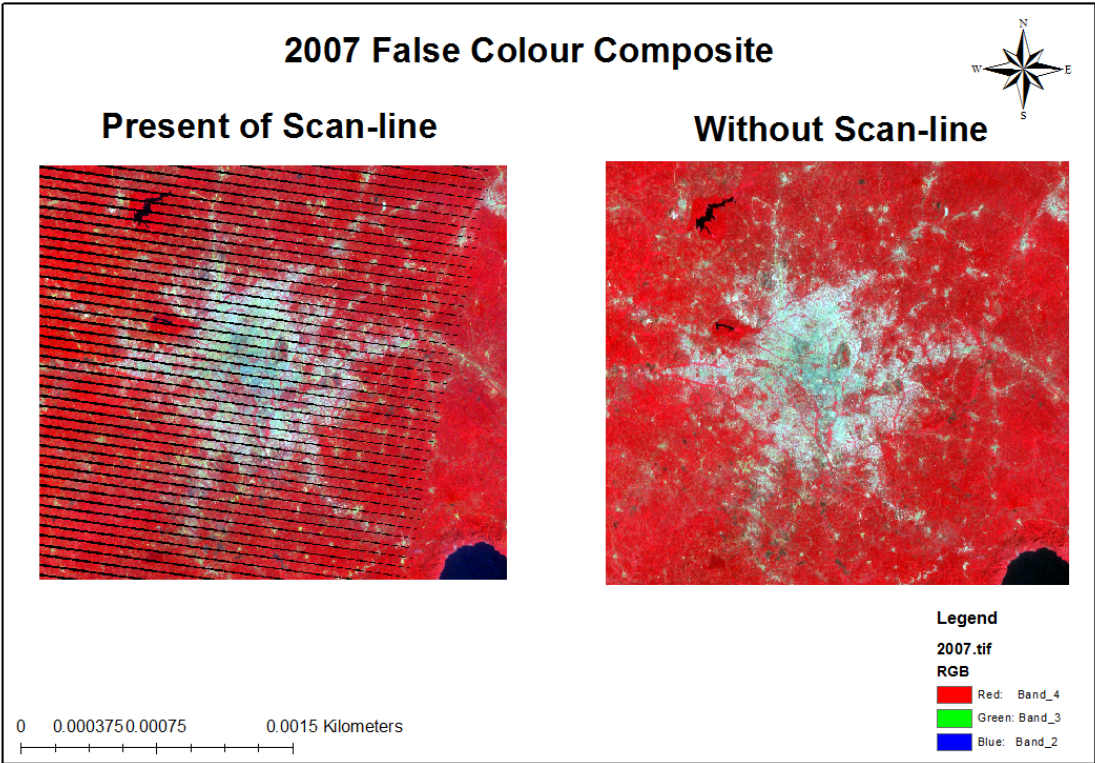
169   Remotely sensed data helped in providing information required for assessing the ecosystems'
170   conditions through land cover mapping [5]. Land cover mapping mimicked the earth surface by
171   delineating the different features that exist in their natural environment, using the image classification
172   technique. For the purpose of this study, forest refers to areas covered with trees (either deciduous or
173   evergreen), built-up areas refer to areas with residential or commercial structures and water bodies
174   refer to areas covered by rivers, ponds, dams, etc.

175   Image Classification method was done for the three images using supervised classification techniques
176   in ArcMap 10.4.1. In this case the training samples were selected based on the reflectance or the
177   spectral characteristics of the classes. This technique gives more accurate results with a higher
178   accuracy than the unsupervised technique [55]. The supervised classification was carried out using
179   Maximum Likelihood Algorithm in ArcMap and selection of the training areas were based on the
180   ground truth points obtained from google earth

181   *2.5. Image Enhancement and Accuracy Assessment*

182   Image enhancement was used to improve the quality of the imagery to make it look more suitable for
183   analysis. The visibility of the imagery, mostly known as colour composite was established using the
184   Landsat bands 432 (i.e. Near-Infrared, Red and Green), this was to obtain a false colour composite.
185   The false colour composite is mostly used in vegetation analysis because plants mostly reflect highly
186   in infrared but emits green colour as seen with the naked eyes. A deep forest reflects in deep red,
187   agriculture in light green, built-up areas in cyan blue, soils vary from dark to light brown and water
188   appears very dark in colour [25]

189   Accuracy assessment was carried out to determine the feasibility of the classified images depending
190   on the level of acceptance of error in the imagery. This is very essential for any classified imagery since
191   all classified images are assumed to be inaccurate to only be used as a decision-based tool. This also
192   served as a guide for the map's quality and reliability. Hence, the accuracy assessment of these
193   classified images were calculated using the Kappa coefficient statistics, K (which is the measure of the
194   level of agreement of the classified image with the reference data) and the error matrix. Thus, a K
195   >0.80 indicates a strong agreement of the class assessed. Whiles a K between 0.40 and 0.80 showed a
196   good agreement, and K <0.40 showed a poor agreement [27]

197   In this study a reference data consisting of 90 text pixels was generated based on a rule of thumb. The
198   rule of thumb states that, there should be 10 times the number pixels for each class as there are all
199   classes. In this case, three (3) classes were identified hence each class contains 30 text pixels with a
200   total 90 text pixels all the three classes (Maps & GIS Library, 2014). This was done in ArcMap 10.4.1
201   and later exported to MS Excel to further determine the kappa matrix (k), the overall accuracy,
202   commission error (user's accuracy) and omission error (producer's accuracy). Overall accuracy is the
203   total accuracy of the classified images. Commission error (user's accuracy) on the other hand is the
204   probability of a specific class that is incorrectly classified, whiles Omission error (producer's accuracy)
205   is the probability of a specific class to be incorrectly classified in the reference data or ground. The
206   formulae used in determining the kappa coefficient, the overall accuracy, user's and producer's
207   accuracy respectively; are given below respectively;

$$K = \frac{\sum_{i=1}^{\gamma} X_{ii} - \sum_{i=1}^{\gamma} (X_{i+} Xx_{+1})}{N^2 - \sum_{i=1}^{\gamma} (X_{i+} Xx_{+1})} \tag{1}$$

$$Overall\,accuracy = \frac{Total\,number\,of\,pixels\,correctly\,classified}{Total\,number\,of\,classified\,cells} X100 \tag{2}$$

$$User's\,accuracy = \frac{Total\,number\,of\,correctly\,cell\,(row)}{Total\,number\,of\,pixel\,in\,a\,given\,class} X100 \tag{3}$$

$$Producer's\,accuracy = \frac{Total\,number\,of\,classified\,cells\,(column)}{Total\,number\,of\,classified\,pixel\,(column)} X100 \tag{4}$$

208 Where N is the total number of observations in the matrix, r is the number of rows in the matrix, x_{ii} is
209 the number of observations in row i, x_{+i} is the total for row i and x_{+i} is the total for column I [27]

210 *2.6. Change Detection Technique*

211 This is the technique used to determine the changes that have occurred in a particular place over a
212 period of time. This process involves the use of multi-spectral and multi-temporal data set which is
213 used to discriminate between the changed areas [37]. The classified images were used in this study to
214 determine the cover change, annual rate of change and the percentage annual rate of change within
215 the years under the study, 1986-2007, 2007-2015 and 1986-2015 respectively. The attribute table of the
216 changed maps were exported to MS Excel based on the following formulae to determine the change
217 detection matrix

$$PercentageChange = \frac{Area_{iYearx+1} - Area_{iYearx}}{\sum_{i=1}^{n} Area_{iYearx}} \tag{5}$$

$$Annual\,rate\,of\,change = \frac{Area_{iYearx+1} - Area_{iYearx}}{t_{Years}} \tag{6}$$

$$Percentage\,Annual\,rate\,of\,change = \frac{Area_{iYearx+1} - Area_{iYearx}}{\sum_{i=1}^{n} Area_{iYearx}\,x\,t_{Years}} \tag{7}$$

218

219 Where; $Area_{iYearx+1}$ = area of land cover(i) for the subsequent year of the following date, $Area_{iYearx}$ =
220 area of land cover(i) for the initial year, $\sum_{i=1}^{n} Area_{iYearx}$ = the sum of the land cover area for the initial
221 year, t_{Years} = the number of years between the initial year and subsequent year [30]

222 *2.7. Climatic Data Analysis*

223 Analysis on the long term temperature and rainfall data over the 55years period (1960 – 2015) over
224 Kumasi and two other towns (Konongo and Ejura) was used. These climatic variables were used
225 because of their tendency to reveal changes in extreme values during the period of study. Annual
226 maximum and minimum temperature and precipitation analyzed over the period was used to
227 establish the historical trends using linear regression equation with inter-annual variability assessed.
228 A 10- year temperature anomaly was used to compare for both the maximum and minimum
229 temperatures over Kumasi, Konongo and Ejura

230 This comparison of the temperature over Kumasi with that of other towns like Konongo and Ejura was
231 made to investigate the presence of the urban heat island effect in Kumasi. Also the urbanization effect
232 of the city is expected to affect the variability of precipitation. The linear trend of precipitation is also
233 calculated using the data measured from the Ghana Meteorological Agency over the period of study

234 **3. Results and Discussion**

235 *3.1. Land Use Change Analysis*

236 Three land cover classes were identified for the land cover classification done to determine the land
237 use and land cover changes that occurred between 1986, 2007 and 2015 respectively within the study
238 area. These include the Forest, Built-up areas and Water body. The classified land cover maps for this
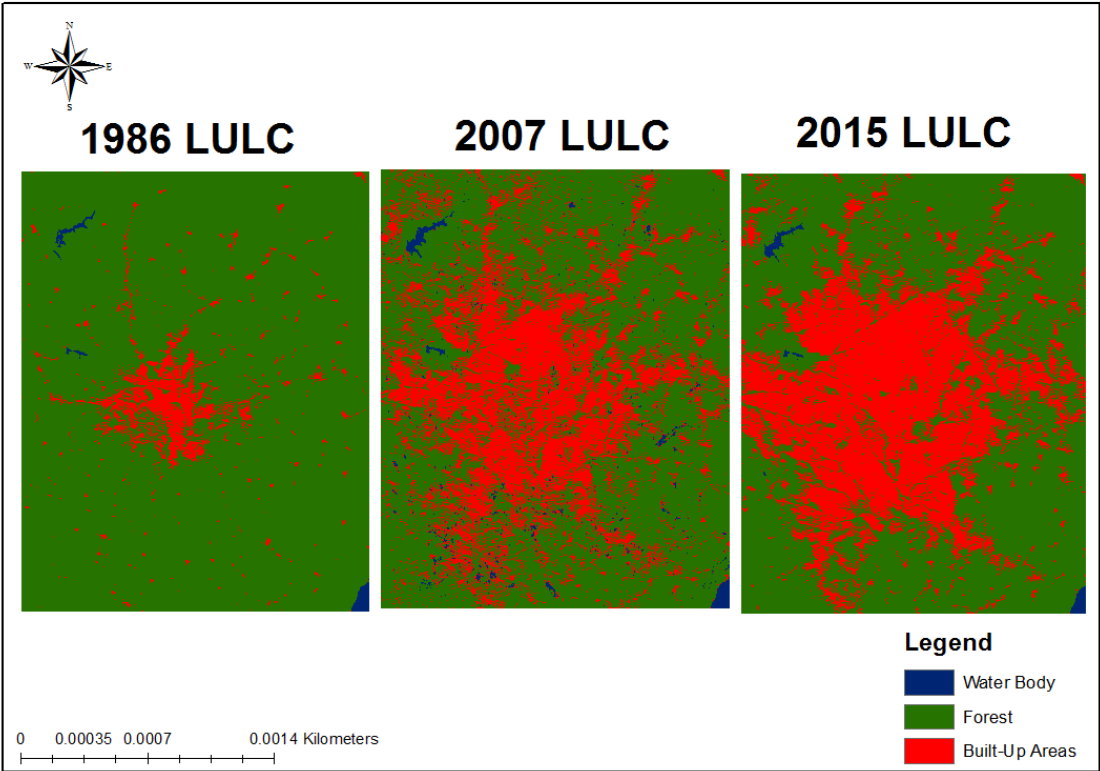239 study are shown in figure4

Figure 4. Classified Land Cover Maps for 1986, 2007 and 2015

240 Acquiring a Landsat images free from cloud cover in Africa especially is a major issue. This is also the
241 reason why the analysis was not able to cover the whole region. However, the image obtained from
242 Landsat for this study had a minimal cloud cover and those containing the clouds too were seen at a
243 small portion with an insignificant effect to the work

244 In 1986 the land cover was mainly dominated with forest, however as population increased the land
245 cover also started changing, as seen in 2007 and 2015 which were mostly dominated with built-up
246 areas. Also from figure 4, the built-up areas were mainly dominated at the the central portion of the
247 region. This shows that most of the activities are seen in the central part of the region as people travel
248 from all walks of life in search of greener pastures in this area. Water body also started increasing from
249 2007 to 2015, indicating that urbanization has a serious impact on the environment. Development in
250 urban areas involves covering the ground with artificial surfaces, therefore increasing the amount of
251 surface runoff as compared to infiltration, evaporation and transpiration which directly affects the
252 hydrological cycle. This is because, surface runoff travels faster on a hard smooth surfaces than it does
253 over a natural surface. However, increase in surface runoff increases the total volume of water
254 reaching the river soon after the rain leading to less been infiltrated into the soil and also causing
255 flooding

3.2. Accuracy Assessment

257 The accuracy assessment of this study was determined based on the equations 1-4 above to compare
258 the classified results with the ground truth data. This was analysed using ArcMap and later exported
259 to Microsoft Excel for further analysis which cannot be done in ArcMap. The table2 shows the error
260 matrix and the total accuracy report for 1986 classified image. The image classified in 1986, had an
261 overall accuracy of 91.1% and kappa coeffiecient of 0.87, indicating that 87% of the classified image is
262 in agreement with the reference data used for assessment

263 In 1986, as shown in table2, water bodies recorded the highest producer accuracy, that is 100%,
264 followed by forest (91.43%) whiles built-up areas recorded the least (83.39%). This indicates that the
265 class "Water" had the highest probability of being correctly classified. Also for the user's accuracy,
266 built-up areas and forest had the highest that is 100% respectively, followed by water body water body
267 75.76% having the least probability. This indicates that, the forest and built-up areas had the highest
268 probability of what was classified on the map actually representing exactly what is on ground

Table 2. Accuracy Assessment for 1986 Land Cover Map

Class Names	Water Body	Forest	Built-Up Area	Classified Total	Error Commission (%)	User's Accuracy (%)
Water Body	25	3	5	33	24.24	75.76
Forest	0	32	0	32	0	100
Built-Up Area	0	0	25	25	0	100
Reference Total	25	35	30	90	-	-
Error Commission(%)	0	8.57	16.67		Overall Accuracy(%)	91.11
Producer's Accuracy(%)	100	91.43	83.33		Kappa Coefficient(%)	0.87

269 In 2007, the overall accuracy recorded was 98.9% with a kappa coeffient 0.99. Thus, 99% of the
270 classified image was in agreement with the reference data used for analysis. The details of the error
271 matrix for the classified image can also be seen in table3. In this year the highest producer's accuracy
272 recorded were water body (100%) and forest (100%), whiles built-up areas recorded the least (96.75%).
273 This however indicates that water body and forest had the highest probability of been correctly
274 classified. This shows that, what was been classified represents what is actually on the ground

Table 3. Accuracy Assessment for 2007 Land Cover Map

Class Names	Water Body	Forest	Built-Up Area	Classified Total	Error Commission (%)	User's Accuracy (%)
Water Body	25	0	1	26	3.85	96.15
Forest	0	35	0	35	0	100
Built-Up Area	0	0	29	29	0	100
Reference Total	25	35	30	90	-	-
Error Commission(%)	0	0	3.33		Overall Accuracy(%)	98.89
Producer's Accuracy(%)	100	100	96.67		Kappa Coefficient(%)	0.99

275 In 2015, the overall accuracy recorded is 85.56% with a kappa coeffient 0.78, indicating a good
276 agreement with reference data. The details of the error matrix for the classified image can be seen in
277 the table4

278 In this year, built-up areas recorded the highest producer's accuracy of 91.43% followed by forest and
279 water body recording 83.33% and 80% respectively. This however indicates that forest and water body
280 had the highest probability of been correctly classified. This shows the percentage level of what is been
281 classified representing what is actually on the ground. Also from the previous years as shown from the
282 table4, 2015 recorded the least overall accuracy and kappa coeffient though it falls within the accepted
283 range. This is due dominance of the built-up areas with a higher reflectance within the research area

Table 4. Accuracy Assessment for 2015 Land Cover Map

Class Names	Water Body	Forest	Built-Up Area	Classified Total	Error Commission (%)	User's Accuracy (%)
Water Body	20	5	0	25	20	80
Forest	5	25	3	33	24.24	75.76
Built-Up Area	0	0	32	32	0	100
Reference Total	25	30	35	90	-	-
Error Commission(%)	20	16.67	8.57		Overall Accuracy(%)	85.56
Producer's Accuracy(%)	80	83.33	91.43		Kappa Coefficient(%)	0.78

284 The overall accuracy for this study was not 100% because of some few misclassifications of pixels
285 which occurred in nearly all the classes. Most of these misclassifications can be attributed to the nature
286 of the image used in terms of clouds and scan lines. Also difficulty in differentiation between the
287 spectral reflectance between water body and forest since most of the water body were covered with
288 trees and some are also found within forest. Using Landsat image with a low resolution makes it
289 difficult as compared with high resolution images which are commercial

290 *3.3. Land Cover Change Detection Analysis due to Urbanization in Kumasi*

291 Change detection analysis shows the changes that have taken place within a given area at a particular
292 period of time from 1986 to 2015. From the table5 and table6, from 1986-2007 most of the areas were
293 converted to built-up areas by 2.23 ha/year followed by water body 0.08 ha/year whiles the forest
294 cover reduced by 2.31 ha/year

Table 5. LULC Change Analysis from 1986 - 2007 (a)

Class Names	LULC 1986		LULC 2007	
	Area (ha)	Cover (%)	Area (ha)	Cover (%)
Water Body	2.62	1.13	4.31	1.87
Forest	218.84	94.63	170.42	73.69
Built-Up Area	9.81	4.24	56.54	24.45
Total	231.27	100.00	231.27	100.00

Table 6. LULC Change Analysis from 1986 - 2007 (b)

Class Names	LULC 1986 - 2007			
	Area Change (ha)	Cover Change (%)	Annual rate of Change(ha/yr)	Annual rate of Change (%/yr)
Water Body	1.70	0.73	0.08	0.03
Forest	-48.42	-20.94	-2.31	-1.00
Built-Up Area	46.73	20.20	2.23	0.96

295 Also from the table7 and table8, from 2007-2015, built-up areas increased by 1.14 ha/year, whiles
296 water body and forest cover decreased by 0.21 ha/year and 0.92 ha/year respectively

Table 7. LULC Change Analysis from 2007 - 2015 (a)

Class Names	LULC 2007		LULC 2015	
	Area (ha)	Cover (%)	Area (ha)	Cover (%)
Water Body	4.31	1.87	2.61	1.13
Forest	170.42	73.69	163.04	70.50
Built-Up Area	56.54	24.45	65.63	28.38
Total	231.27	100.00	231.27	100.00

Table 8. LULC Change Analysis from 2007 - 2015 (b)

Class Names	LULC 2007 - 2015			
	Area Change (ha)	Cover Change (%)	Annual rate of Change(ha/yr)	Annual rate of Change (%/yr)
Water Body	-1.71	0.74	-0.21	-0.09
Forest	-7.38	-3.19	-0.92	-0.40
Built-Up Area	9.08	3.93	1.14	0.49

297 It can be seen that there has been a tremendous change in the study area from 1986-2015 as shown in
298 table9 and table10. From this period there has been a continuous increase in built-up areas by 1.92
299 ha/year with an indirect decreasing in forest cover of 1.92 ha/year and water body 0.21 ha/year

Table 9. LULC Change Analysis from 1986 - 2015 (a)

Class Names	LULC 1986		LULC 2015	
	Area (ha)	Cover (%)	Area (ha)	Cover (%)
Water Body	2.62	1.13	2.61	1.13
Forest	218.84	94.63	163.04	70.50
Built-Up Area	9.81	4.24	65.63	28.38
Total	231.27	100.00	231.27	100.00

Table 10. LULC Change Analysis from 1986 - 2015 (b)

Class Names	LULC 1986 - 2015			
	Area Change (ha)	Cover Change (%)	Annual rate of Change(ha/yr)	Annual rate of Change (%/yr)
Water Body	0.00	0.00	-0.21	0.00
Forest	-55.80	-24.13	-1.92	-0.83
Built-Up Area	55.81	24.13	1.92	0.83

300   Figure5 shows the graphical trend of the land cover changes from 1986 – 2015 for all the classes at
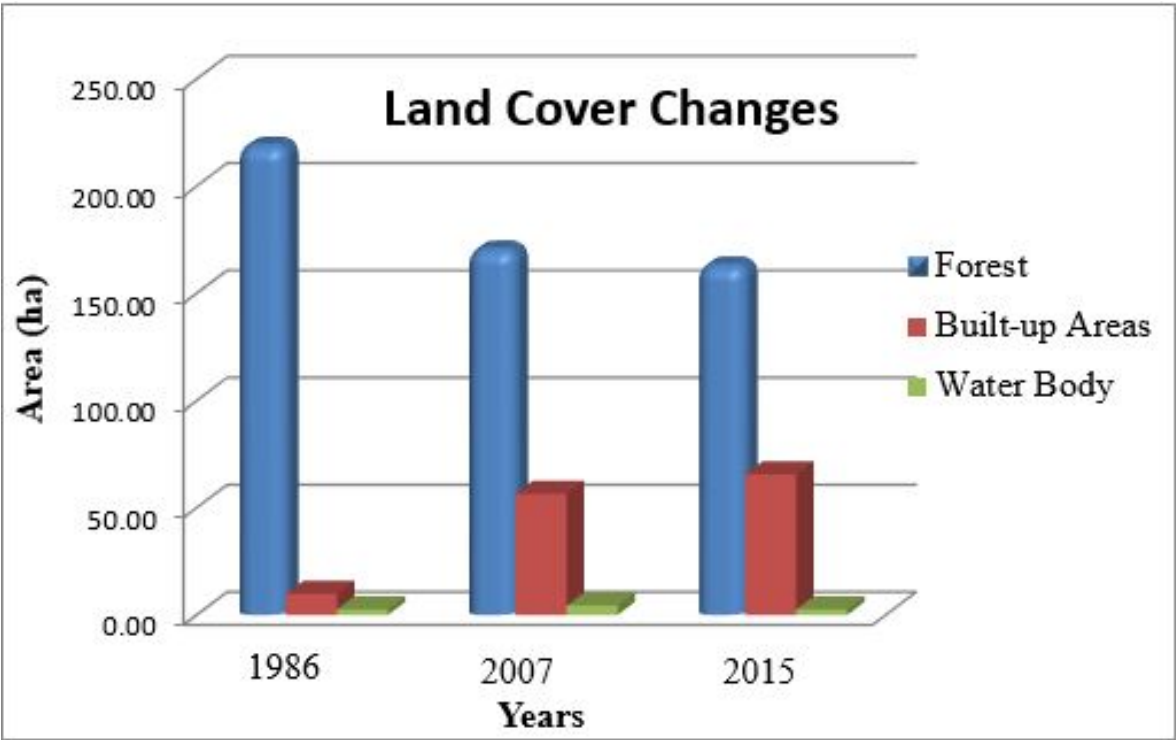301   different period as seen in table5 to table10

Figure 5. Graphical Representation of the Land Cover Changes

302 Land cover change detection was analyzed using the post classification change detection approach
303 which deals with the comparison of two independently classified land cover maps from two different
304 dates. According to studies by [33], the causes of the land use land cover change highlights the
305 concerns of the research agenda on the global environmental changes several decades ago. This is due
306 to the fact that land cover changes influence climate change, ecosystems and the ability of biological
307 systems to support human needs in terms of ecosystem goods and services

308 In this study, the main land covers are the forest, water body and built-up areas. The change detection
309 from 1986 to 2015 indicates the decreasing rate of the forest cover with a slight increase in water body
310 over a period of time with also increasing rate in built-up areas. This helped showed the trend of the
311 forest cover change as the years increased in the study area. In this case the annual rate of change
312 occurring in the study area for the period of 1986 to 2015 was calculated. The highest forest cover loss
313 was recorded in 1986 to 2007, of about 20.94% of the total area experiencing forest loss. 20.24% of the
314 forest area was converted into built-up area which led to the forest cover loss within this period. This
315 forest loss can be attributed to the weak law enforcement and less control mechanism within this
316 period. Moreover, this change may be attributed to population increase, hence the demand for
317 accommodation. Also land owners sell their land mostly agricultural lands and forest areas to housing
318 or real estate developers due to the huge amount of money paid by the developers

319 Earlier study by [32], on the loss of the green vegetation to the built- up areas, attributed the main
320 cause to the conversion of these places to houses and buildings to meet the accommodation needs of
321 the rising population in Kumasi a result of urban migration. Increased farming activities and
322 uncontrolled illegal mining activities led to the clearing and destruction of the green vegetation. These
323 classified Landsat imageries showed how the city had rapidly extended outward showing a high
324 occurence of urban sprawl. Other studies by [11] and [54], over Kumasi affirmed this by explaining
325 how the urban sprawl had taken up a large area of the city's green vegetation. Consequently, the large
326 green vegetation area that used to exist over the city has drastically been reduced, casting a negative
327 image on the 'Garden city' of Kumasi

328 *3.4. Population Growth of the City*

329 From the 2010 Population and Housing Census conducted by the Ghana Statistical Service, Ashanti
330 Region recorded a population of 4,780,380 in 2010 as compared to the 3,612,950 in 2000, with the
331 Kumasi Metropolis recording a population of 1,730,249 in 2010 as against 1,170,270 in 2000. The
332 statistics (as shown below) shows an intercensal growth rate of 8.76% in population for Kumasi in 2000
333 and a 3.91% further growth rate for 2010. Kumasi is also home to about 39.49% of the total population
334 in the Ashanti Region and about 7.65% in Ghana. These statistical records show how populated the
335 city continues to be, and the need for its expansion to accommodate the growing population [22]

336 The uncontrolled extension of the city fundamentally through high rate of lodging advancements put
337 much pressure on numerous nature reserves and destroys the rich green vegetation that had been
338 protected throughout the years. The land area of Kumasi in 1950 was just 25km^2 but due to the quick
339 urban sprawl, the city had extended outward to around 182km^2 in 1963 and as at 2011, the city has
340 further extended past its limits to cover an area of approximately 254km^2 [50]. A comparable study by
341 [7] over Melbourne (another garden city) showed that the city had greatly expanded due to urban
342 sprawl. This also had a negative effect on the green vegetation or spaces which used to exist in the city
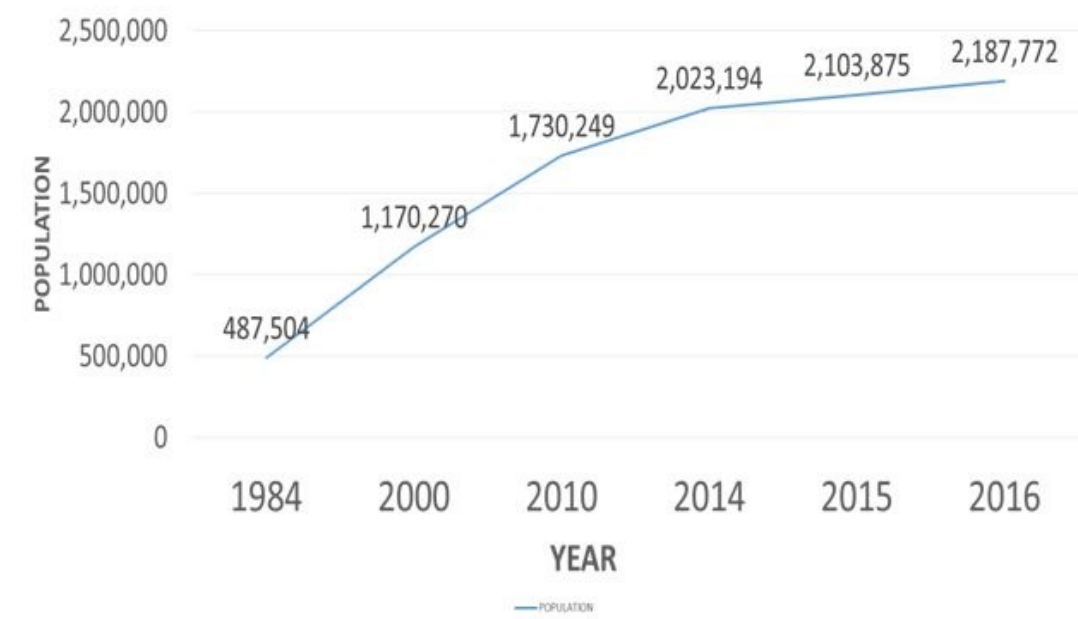
Figure 6. Population of Kumasi since 1984 (Source: Kumasi Metropolitan Assembly, 2016

₃₄₃ *3.5. Micro- Climatic response to Urbanization 1960 - 2015*

₃₄₄ 3.5.1. Temperature Trend

₃₄₅ Figure7 shows the departure of the annual mean temperature from the average during 1960 – 1990 at
₃₄₆ Kumasi compared to two other surrounding towns (Konongo and Ejura), in the Ashanti region but
₃₄₇ 53km and 100km away from Kumasi respectively. These surrounding towns have a good considerable
₃₄₈ green vegetation cover as compared to Kumasi. The linear increasing trend of the mean temperature
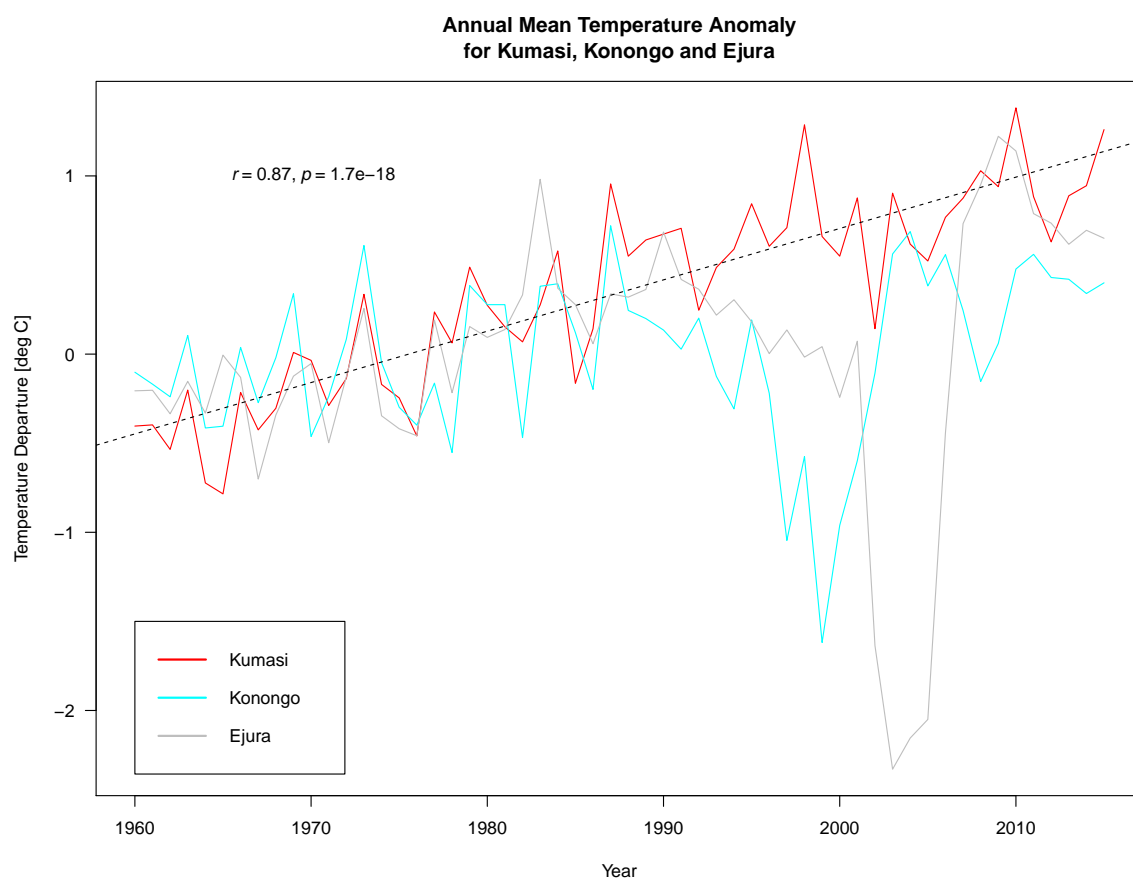₃₄₉ at Kumasi is 1.2 °C/ 55 years, with 1.0 °C/ 55 years for Ejura and 0.2 °C/ 55 years for Konongo

Figure 7. Mean Surface Temperature Departures for Kumasi, Konongo and Ejura

350 The rate of increase of the daily minimum temperature at Kumasi (1.55°C/ 55 years) was slightly
351 lesser than the rate of change for the daily maximum temperature (1.78°C/ 55 years), from 1960- 2015,
352 showing a decreased daily range. The rapid urban warming of Kumasi differs from that of other cities
353 in Europe and North America, with recent rise in temperatures not conspicuous in spite of the
354 existence of heat islands [29,49]. It was observed from the analysis that 1965 was relatively the coldest
355 year with an average annual temperature of 25.25°C within the period of study, whilst 2010 recorded
356 relatively the warmest average mean temperature of 27.41°C within the period of study too

357 A possible explanation for this difference and increase in temperatures as showed from both the mean
358 surface temperature analysis for Kumasi and its surrounding cities has been the significant change in
359 landscape of Kumasi from the 'Garden city' model, which has also been supported by the analyzed
360 Landsat images. This has been as a result of the rapid growth of the city with increase in population
361 and built environments (homes and industries made up of impervious layers like concrete, black
362 asphalt, bricks and stones)

363 The relatively hot season observed for Kumasi usually lasts from March to April with an average daily
364 temperature of 32°C. Whiles the relatively cool season also lasts from June to October annually, with
365 average daily temperature of 28°C. Further analysis showed that the maximum temperatures recorded
366 for Kumasi within the hot period, especially for March showed a significant increase in temperature,
367 with August also exhibiting a substantial rise in its minimum temperatures for the same period as
368 shown in figure**??** and figure**??** respectively

369 Most studies done on urban heat islands have also established the warmth associated with cold
370 seasons, when there is strong nocturnal inversion in rural areas, although there could also be some
371 effects from topography and micro- scale weather effects [57]. The possibility of an urban bias in
372 long-term temperature data is not only limited to large cities because heat islands can even occur for
373 smaller cities with huge population. Ejura and Konongo were selected for this research because they
374 were considered not to have been much influenced by urbanization and had a lesser population as
375 compared with Kumasi. These two cities too have a greater percentage of green vegetation than
376 Kumasi and are also found within the Ashanti region

377 Long- term temperature records from urban towns in Ghana have shown a substantial warming trend,
378 especially for Kumasi and Accra [38]. Other non-weather microscale factors could be responsible for
379 these observed temperature changes. For the case of Kumasi, construction of these built-up
380 environment (buildings, roads, etc), have greatly contributed to the changes of these temperatures
381 within the city. Some of these tall buildings erected within the city also decrease the exposure of the
382 city to wind and upward heat diffusion, which also results in temperature rise

383 3.5.2. Precipitation Trend

384 Kumasi is situated in the wet semi-equatorial region of Ghana. The climate of the city is characterized
385 by two rainfall seasons with annual mean rainfall between 1250mm and 2000mm. The precipitation
386 trend for the city within the 55- year period has also not changed much but show annual variation
387 (figure8)

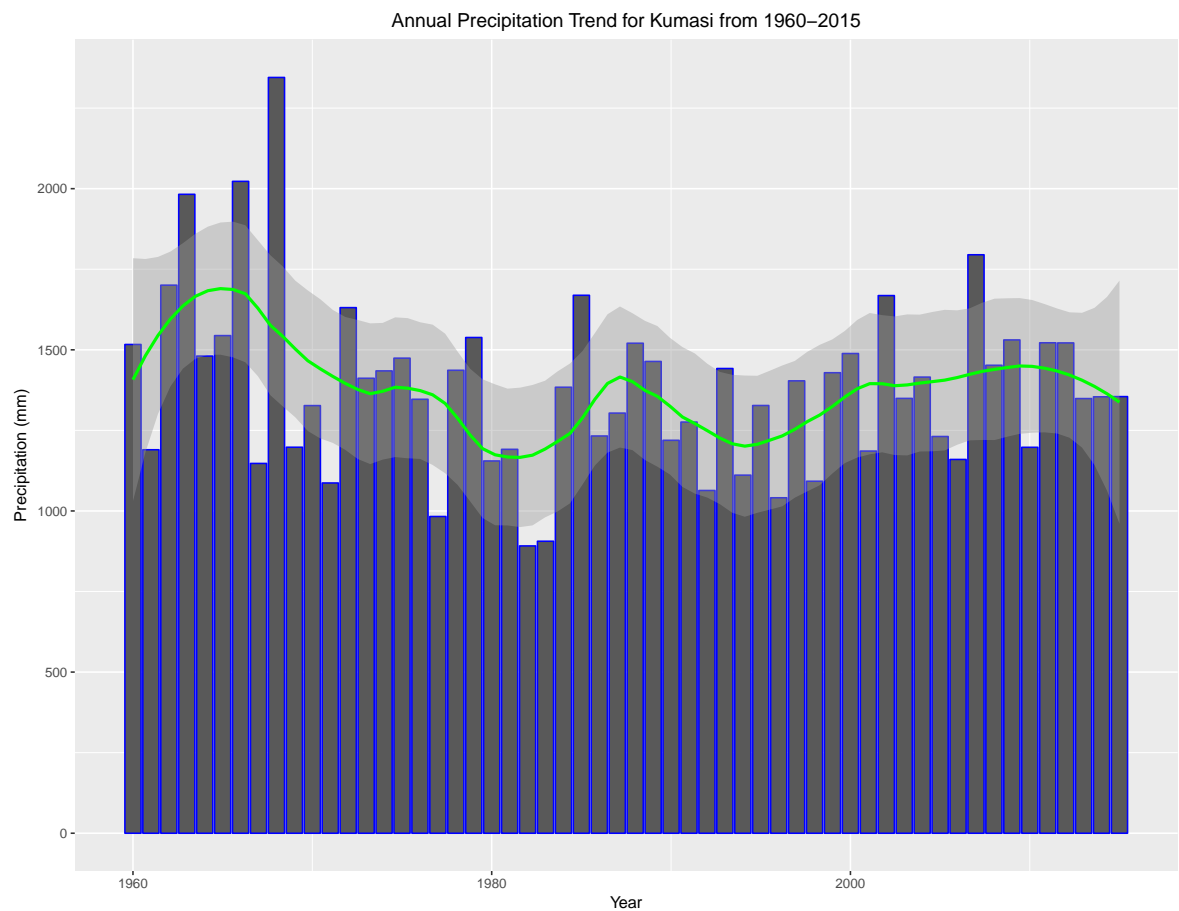Annual Precipitation Trend for Kumasi from 1960–2015

Figure 8. Annual Precipitation Observed over Kumasi from 1960 - 2015

388   The analysis also shows that the relatively wet year for Kumasi was in 1966, with an annual mean
389   rainfall amount of 2,345mm. Whiles, 1982 and 1983 recorded the least annual mean rainfall over the
390   city. The dryness for the year was not associated with the urbanization but to the El Niño Southern
391   Oscillation (ENSO) effect, which affected Ghana's rainfall season that year. The ENSO effect of 1982-
392   1983 strongly affected most areas of the country causing severe droughts and famine [1]. However,
393   variability in rainfall observed over the city is expected to affect the agricultural planning for farmers
394   within the region, as shifts in the onset and length of the rainy season will have major impacts on crop
395   production. Some rainy seasons have been observed to start late but end shortly, whiles other rainy
396   seasons for some years experienced long dry spells that largely affected crop productivity or yield [43]

397   With most green parts of the city already lost to construction of buildings and traffic, leading to
398   increase in temperature, other secondary effects on the local meteorology and change in the local wind
399   patterns and humidity will vary strongly. Frequent variability in rainfall will lead to extreme weather
400   conditions from drought to flood periods. The presence of vegetation cools the surrounding air
401   through transpiration and enhances the evaporative cooling effect within the city [46]. Other studies
402   have shown that large urban cities experiencing the urban heat effect are characterized by lower
403   relative humidity than its surrounding areas due to the impervious surfaces, which results in a slightly
404   lower heat index [6,14,19]. This causes reduced evapotranspiration and greater runoff, which results
405   to higher temperatures but lower relative humidity [23]

4. Conclusion and Recommendations

407   This research utilized remote sensing data to identify the land use land cover changes between 1986
408   and 2015 within the study area. The trend of the forest cover loss within the study area could be
409   attributed to the conversion of the forest cover to the expansion of built-up areas. This has
410   significantly increased the water body as artificial surfaces are created in the urban areas, hence
411   leading the high runoff generated with less infiltration rate. Also most of the water body find their
412   source from these mountainous and forested areas, however resulting in some water body within the
413   forest area getting dried up due to deforestation. Ecosystem activities are interlinked together hence
414   the activity of one can directly or indirectly affect the ecosystem. Therefore, the conversion scenarios
415   are very keen for the stakeholder to better understand the environment and for sustainable
416   implementations. Forest areas can be protected from invasion by people leaving around for sand
417   winning activities, farming and built-up operations

418   Most researches have indicated that the use of RS data and GIS technique is a valuable tool in
419   analyzing, locating and predicting the land cover change. RS data could aid in the forest cover change
420   detection and also help identify areas that are under high risk of invasions. This study has shown that
421   the land use land cover is changing at an increasing rate within the study area as population also
422   increases. Therefore, if the current trend continues without any measures been put in place to reduce
423   the situation, then there could be an imbalance in the ecosystem

424   Urban warming as a result of the recent change in land use observed over Kumasi, has resulted in the
425   alteration of the heat balance within the metropolis through anthropogenic activities, such as
426   destruction of vegetative cover to create impervious layers of the built environment, combustion of
427   fuel from domestic heating purposes, factories and traffic. This has reduced the potential for
428   evapotranspiration, and contributed to the conversion of energy into sensible heat than latent heat [47].
429   The study also showed a gradual but significant increase in air temperatures for Kumasi within the
430   period of the study (1960 – 2015), causing rippling effects on other micro- climatic variables, posing
431   much threat to the health of the inhabitants. It's worth noting that these trends are expected to rise,
432   considering the recent global warming trend and an annual mean growth rate of 4.87% for most urban
433   cities in Africa [59]. The enhanced effect of urbanization will have more negative impact on the both
434   the weather and climate of these cities and the urban ecosystem, if the proper climate change
435   mitigation and adaptive policies are not put in place by city planners [38]. Analysis of the long term
436   climatic data for Kumasi from 1960 – 2015, considered for this study, showed a general increasing
437   trend. The rate of increase of the daily minimum temperature at Kumasi (1.55°C/ 55 years) was
438   slightly lesser than the rate of change for the daily maximum temperature (1.78°C/ 55 years) over the
439   55-year period. This shows a decrease in the daily mean temperature range

440 Consequently, further increase in air temperatures, especially for nighttime, will be unbearable.
441 Usually, tall buildings and impervious materials associated with the built-up environment heats the
442 air trapped between them and prevent the outgoing thermal radiation from escaping these urban
443 areas. This also affects the air quality and flow within these urban areas characterized with urban heat
444 islands. The production of ozone at the surface level due to higher concentrations of volatile organic
445 compounds, carbon monoxide, nitrogen oxides and other particulate matter from anthropogenic
446 activities will be enhanced. Urban residents may resolve to cooling systems which will increase the
447 energy demand of the city. Intense heat will also increase other respiratory diseases through bad air
448 quality especially for places with poor ventilation systems. Outbreaks of respiratory and other
449 diseases is more likely in the highly populated areas of Kumasi. Recent outbreak of the acute
450 respiratory illness (H1N1) in the Kumasi metropolis, which was confirmed by the Ghana Health
451 Service in the Kumasi, through a report by Ghana News Agency on 7th December 2017, showed that 4
452 death cases were recorded as against 44 reported cases. This is a clear sign of such effects due to
453 urbanization. Also, the observed rise in temperature will affect the human body's ability to
454 thermos-regulate and theoretically increase the risk of mortality through heat stress. Thermal stress
455 will not only cause discomfort but indirectly lead to reduced mental and physical performance that
456 will affect physiological and behavioural changes

457 Moreover, variability in rainfall as explained earlier will lead to years characterized with either
458 drought or flood conditions. Thus, poor city drainage system and poor waste management system as
459 observed in Kumasi, will lead to choking of gutters, which can further block the passage to lead to
460 frequent flood events in the city. These flood events can lead to destruction to properties and life. Also,
461 water quality is also expected to be affected, as during stormy or rainy conditions, hot pavements and
462 rooftops transfer excess heat to rain water. This could drain into sewers and raise the water
463 temperature in streams, rivers, lakes and ponds, further causing harm to aquatic life. This thermal
464 pollution will increase water temperature and create thermal stress and shock for these aquatic species

465 As such, with the proper mitigation and adaptive policies put in place by the city planners, the effect
466 of urban heat islands will be minimized. The adoption to white or reflective materials to build houses,
467 roofs, pavements and roads to increase the overall albedo effect of the city is advisable. The
468 application of such cool roofs (made from reflective materials), reflective glass, green roofs and light
469 colored concrete will aid in reflecting up to 50% more light and reduce ambient temperature. Green
470 roofs will be excellent insulators during warmer months and cool the surrounding environment. The
471 planting of deciduous trees and creation of green parks around the city will decrease the urban heat
472 island effect. Air quality will also be enhanced as these plants absorb more of the atmospheric carbon
473 dioxide (CO_2). Siting of buildings should be planned in ways to also allow the free movement of air
474 flow within the city, to improve ventilation and air quality. Adherence to other climate change
475 mitigation and adaptive policies like the application of renewable energy sources such as solar or
476 biofuel technologies to meet the energy demand of urban cities like Kumasi, will limit the combustion
477 of fossil fuels and reduce its harmful effects on the environment

478 Finally, regulations or legal frameworks needed to protect the remaining green parks and trees around
479 the city should be set- up and rightly enforced to prevent further destruction to these green spaces.
480 Inhabitants need to be educated on the importance of these green spaces in helping regulate the
481 temperature within the city. This work is a contribution to environmental sustainability especially in
482 modern cities like Kumasi. Further studies using other key technologies to better explain the effect of
483 urbanization on the city's landscape is highly recommended, as Kumasi city planners need to be
484 aware of the threat being posed, and encourage the use of environmentally friendly materials in
485 construction, whiles still ensuring more green spaces especially at commercial areas

487 **Conflicts of Interest:** The authors declare no conflict of interest.

488 **Abbreviations**
489 The following abbreviations are used in this manuscript:
490

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	linear dichroism

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