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A Nexus between Carbon Emissions and Land Surface Temperature in the Six Ecological Zones of Nigeria

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Abstract

The increase in the emission of carbon dioxide (CO_2) in the atmosphere has been identified as a driving cause of global climate change which is a threat to the normal functioning of human and natural systems. Therefore, this study investigated the relationship between the emissions of CO_2 and land surface temperature (LST) in the six ecological zones of Nigeria. High resolution satellite imageries of land surface temperature and carbon were downloaded from the website of the National Aeronautics and Space Administration (NASA) between January 2002 and December 2012 and were utilized for the study. The data were processed using Arc Map version 10.2. Values of the LST and carbon were exported for use in Microsoft Excel software where the relationships were established. The value of LST during the study period ranged between 22.07 °C and 27.24 °C, while the concentrations of CO_2 ranged between 381.6 ppm and 382.27 ppm. The study showed a positive relationship between LST and CO_2 with a coefficient of determination of 37.1%. Both LST and CO_2 increased during the study period. However, an inverse relationship was observed in the freshwater swamp forest ($R^2 = 0.42$) and mangrove forest ($R^2 = 0.21$). The study concluded that the emission of CO_2 and LST increased from the coast to the hinterland during the period of study. It is recommended that the felling of trees be discouraged in the various ecological zones to enhance carbon sequestration and thus reduce the adverse impacts of climate change.

Keywords: Carbon dioxide; Emission; Climate change; Surface temperature; Ecological zone

Introduction

Land provides the basis for human livelihoods and well-being. Human activities have led to the increase of greenhouse gases in the atmosphere; this has consequently influenced the climate system (IPCC 2007). Mendelsohn and Dinar (2009) and Mwaniki (2015) reported that changes in land use and land cover have effects on the climate, while Findell et al. (2017) also noted that land use and land cover change impact on regional climate extremes. Carbon dioxide is the most important of the greenhouse gases in terms of its contribution to global warming, which has produced about 70% of the enhanced greenhouse effect (Houghton 2005). Although carbon is the core element for life on earth, the rate of increase in atmospheric CO_2 is alarming. The carbon dioxide emissions have been increasing globally due to the increase in the consumption of fossil fuels by emerging economies (Olivier et al. 2014). The Intergovernmental Panel on Climate Change (IPCC) (2007) reported that the radiative forcing from increasing atmospheric CO_2 since the Industrial revolution has increased significantly. The IPCC (2013) also noted that global temperatures have risen by 0.85 °C in the last 100 years. Though, Chilingar et al. (2008) reported that accumulation of large amounts of carbon dioxide in the atmosphere leads to cooling and not warming of the climate, several studies have attributed the increase in global temperature to increase in atmospheric CO_2 (IPCC 2007, IPCC 2014). Schmithüsen et al. (2015) reported that CO_2 like other greenhouse gases absorbs surface radiation and causes emission from the atmosphere into the space. The IPCC (2014) reported that as a result of the increased concentrations of CO_2 in the atmosphere, the global mean surface temperature would increase by 3-5 °C. The warming effect of CO_2 emissions is realized within a decade after release but persists for centuries or millennia (Ekwurzel et al. 2017). Mahmood et al. (2019) noted that the best-known indicator of a warming climate is rise in global average surface temperature. Climate and weather variability are projected to increase as the planet warms (Thorton et al. 2014). As a result of rising temperatures, there are changes in weather patterns, ocean currents, regularity of natural habitats and biodiversity (McGuigan et al. 2002). Several studies on the earth's climate have reported that the recent global warming will continue in the future in response to elevated atmospheric greenhouse gases which is an indication that temperature will increase over large areas of the world (Matthews and Caldeira 2008, Solomon et al. 2009). Global temperature increase is expected to bring about changes in precipitation in many regions of the world, increase in global sea level, reduction in crop yields and increase in wildfire in many parts of the Western United States as well as threats of coastal flooding. It has been predicted that warming across Africa is expected to continue with an increase of 0.2% to more than 0.55% per decade (Hulme et al. 2001, IPCC 2001).

According to the IPCC (2007, 2011 and 2012), climate change is real and Africa is the most vulnerable continent. The African continent is the most vulnerable to climate change due to high dependence on rain-fed agriculture, widespread poverty and weak adaptive capacity. The variable climate in Africa is one of the factors posing a threat to the development of the continent. Climate change has a significant impact on biodiversity and ecosystem services in the African continent (Matata and Adan 2018). Already, crop yields are being reduced while crop failure and loss of livestock are being experienced as a result of severe and prolonged droughts, flooding, and loss of arable land due to desertification and soil erosion (Tadese 2010). It is also noteworthy to note that changes are already being observed in ecosystems and human health, while increased water stress is being experienced (Boko et al 2007). There have been several studies on the increase in surface temperature in Nigeria (Ayanlade 2016, Oderinde 2017, Igun and Williams 2018), but there have not been appreciable studies on the relationships between carbon emission and surface temperature. It is against this background that this study was undertaken to investigate the relationship between carbon emissions and surface temperature in the ecological zones of Nigeria.

Materials and Methods

Study area

The study was carried out in the six ecological zones of Nigeria. Nigeria is located in the West African sub-region, south of the Sahara between latitude 4° and 14° N and longitude 3° and 15° E and covers a land area of 923,769 km^2. It is bounded by the gulf of Guinea in the South, Cameroon and Chad in the east, Niger in the North and Benin in the west. The country enjoys the tropical climate but there are wide variations in different parts of the country. Two main seasons are experienced in the country, dry and wet seasons. The dry season is influenced by the Tropical Continental airmass (cT) which originates from the Sahara desert, while the wet season is mainly influenced by the Tropical maritime (mT) airmass originating from the Atlantic Ocean. The maximum mean temperature of about 30.5 °C is experienced in the coastal belt to the south and 34.4 °C in the north, with a normal decrease of about 1.4 °C per 300 m of altitude. A minimum mean temperature of about 22.2 °C is experienced over most of the southern part, falling to 18.8 °C in the north. The warmest months are February, March and April in the south and March to June in the north. Rainfall distribution varies from about 500 mm in the northern fringes of the country to over 3000 mm in the eastern section of the coast in the south (Odekunle and Adejuwon 2007).

Nigeria's climate, like the global climate has been characterized by variations. The average annual temperature over the country has been increasing at a rate of 0.01 °C annually (Adelekan 2000). Weather extremes such as severe rainstorms, intense harmattan, haze and excessive heat causing considerable socio-economic effects have become common across the country. Nigeria's natural vegetation reflects the country's climate and topography diversity. The main determinants of the distribution of vegetation types are the amount of rainfall, relative humidity and length of dry season. The vegetation cover can be broadly grouped into two: the tropical forests and the savannas. Nine major ecological zones can be recognized in the country (Figure 1).

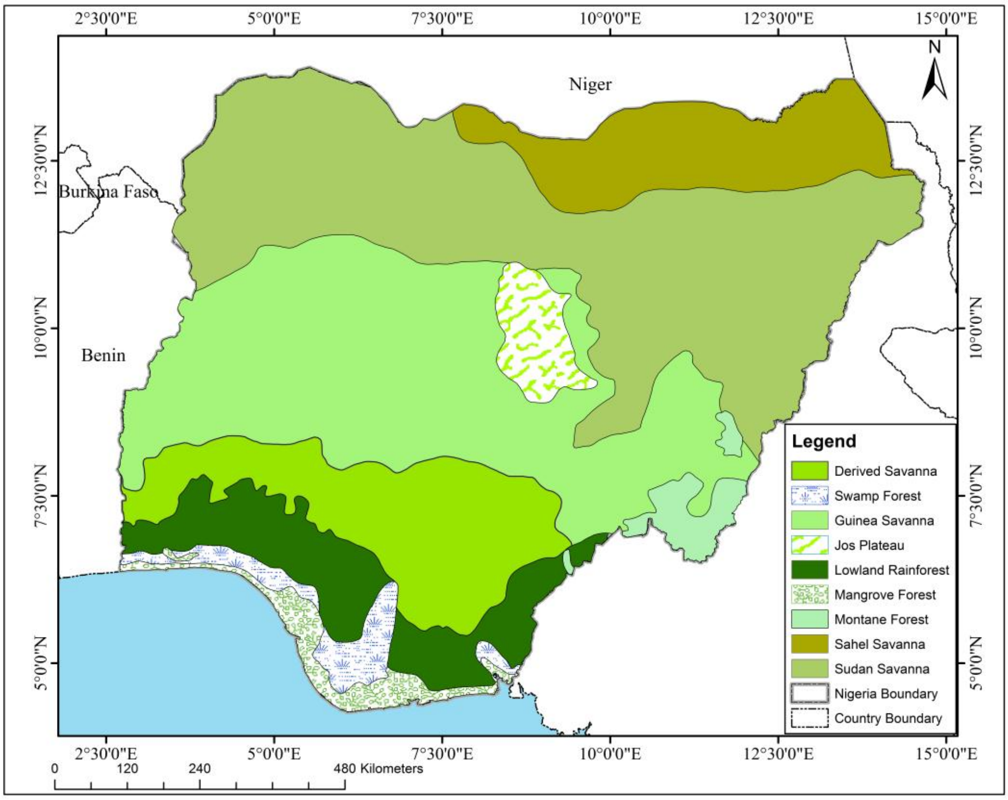

Figure 1: Nigeria ecological zones. Source: Federal Ministry of Environment 2016.

The study utilized two different high-resolution satellite imageries; these are land surface temperature and carbon dioxide data. The land surface temperature data was downloaded from the National Aeronautics and Space Administration Near Earth

Observation website, while the carbon data was obtained from the Goddard Earth Science and Information centre. The datasets are displayed in Table 1.

Table 1: Datasets obtained for the study

Dataset	**Data type**	**Data source**
Administrative map of Nigeria	Vector	Office of the Surveyor General of the Federation (OSGOF)
Ecological zones map of Nigeria	Vector	Federal Ministry of environment (Department of Forestry)
Land surface temperature [day &night] (1 month–Terra/MODIS) 0.05 degree (5,600 meters spatial resolution); latitude/longitude Climate Modeling Grid (CMG) with 7,200 columns and 3,600 rows representing the entire globe. Band 31,32; Monthly Revisiting Time	Raster Digital Data	NASA Earth Observatory (https://neo.sci.gsfc.nasa.gov)
AIRS/Aqua Level 3 Monthly CO_2 in the free troposphere (AIRS+AMSU); 2.5 degrees x 2.5 degrees spatial resolution; latitude/longitude Climate Modeling Grid (CMG) with 7,200 columns and 3,600 rows representing the entire globe; Monthly revisiting time	Raster Digital Data	Goddard Earth Science Data and Information Services Center (GES DISC)

Image processing and analysis

The downloaded imageries were of global scale and were later downscaled using the administrative boundary of Nigeria as the limit. The LST imageries obtained were on monthly basis, the data downloaded was from January to December (year 2002 – 2012).The data were processed and analyzed using Arcmap version 10.2. Each of the downscaled monthly data (LST Day) were imported into Arcmap environment, and were stacked together using the cell statistic geo-processing tool, to produce an annual dataset. The process was repeated for land surface temperature (night), and both the day and night dataset were averaged using the cell statistics geo-processing tool (Enaruvbe and Atafo 2016). The stacked data (years 2002 – 2012) were all re-stacked together to produce a single land surface temperature (day). The process was repeated to derive LST (Night); both the LST (day and night) were averaged to produce the final LST map. The carbon data were processed and analyzed the same way as the LST data, only that the day data was separated from the night data (https://neo.sci.gsfc.nasa.gov).

The relationship that exists between carbon in the atmosphere and LST was determined by creating a random point using the administrative map of Nigeria as the constraining feature data. Thus, values were extracted to the created points from both the LST and carbon result. These values were exported for use in Microsoft Excel software, where the relationship was computed. The annual trend of both the LST and carbon were determined by using the zonal statistics geo-processing tool of the Arcmap software to derive the mean values for each year's dataset, the mean values were saved as (.dbf), and subsequently exported into Microsoft Excel, where the trend was computed (Soni 2017).

Results and Discussion

Spatial variation in the land surface temperature and carbon across ecological zones

Figures 2 & 3 show the variations in land surface temperature and carbon dioxide in the ecological zones in the country, respectively. The land surface temperature was between 20.12 °C and 22.9 °C in the lowland rainforest and the freshwater swamp forest. In the derived savanna ecological zone, the land surface temperature was between 22.91 °C and 23.86 °C.

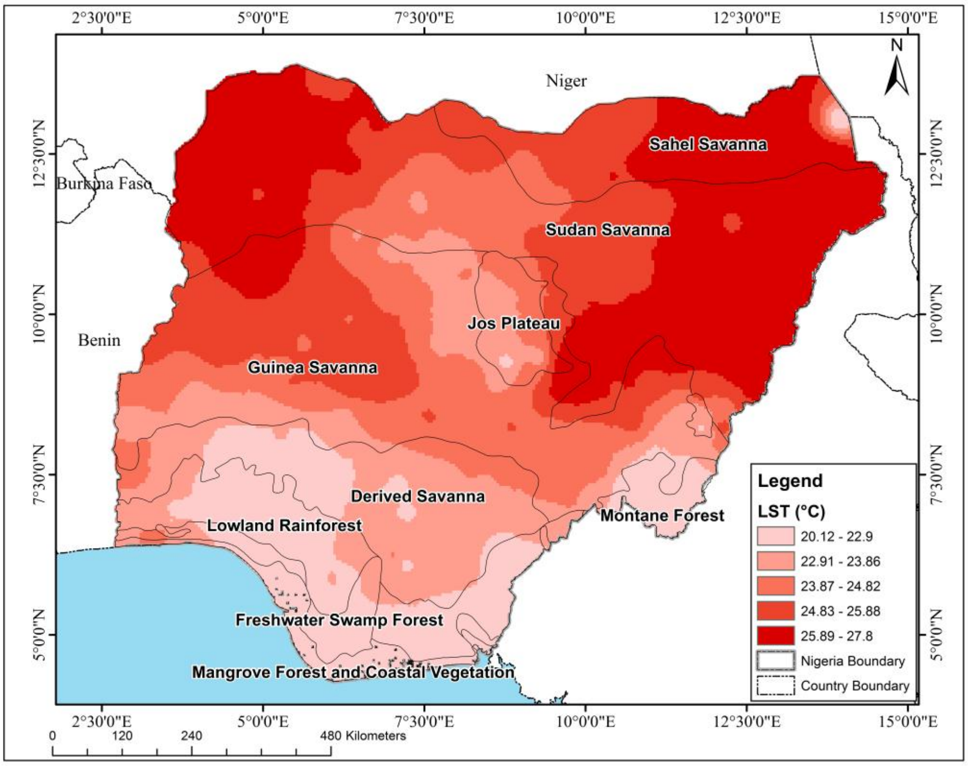

Figure 2: Land surface temperature variations across the six ecological zones of Nigeria.

In the western side of the Guinea savanna, the LST was observed to be between 24.83 °C and 25.88 °C, while on the eastern side it was between 23.87 °C and 24.82 °C. However, in the Sudan savanna, values of 24.83 °C to 25.88 °C were recorded. The highest LST of between 25.89 °C and 27.8 °C was recorded in the Sahel savanna zone. On the montane vegetation, the LST values recorded were between 20.12 °C and 22.9 °C which is similar to what was observed in the lowland rainforest and freshwater swamp forest. The LST observed on the Jos Plateau was similar to that in the derived savanna zone. This shows that the LST increased from the coast to the North. This may be attributed to the decrease in vegetal cover from the coast to the hinterland. Mantey et al. (2014) noted that vegetation provides shade and its removal brings about high LST. This result further corroborates the findings of Igun and Williams (2018) on the impacts of vegetation on the LST. It was also observed that the LST varied within the same ecological zone as was observed in the Guinea savanna. This may be as a result of changes in land use and land cover within the same ecological zone as reported by Abbas et al. (2019). Carbon dioxide emissions were also observed to vary among the ecological zones. The rates of carbon dioxide emissions were between 381.6 ppm and 381.7 ppm in the lowland rainforest, the derived savanna, guinea savanna and the freshwater swamp forest. The rates were 381.8 ppm to 381.9 ppm in some parts of the Guinea savanna and the Jos Plateau. However, 382 ppm of carbon were emitted from the montane forest and part of the Sudan savanna. Furthermore, 382.1 ppm were emitted from some parts of the Guinea savanna while 382.2 ppm to 382.3 ppm were emitted from the Sahel savanna. The rates of emissions were observed to have increased from the coast into the hinterland. The increase in the emissions of carbon dioxide towards the hinterland may be associated with the different land management practices such as bush burning and grazing which leads to the release of carbon into the atmosphere. Isichei et al. (1995) reported that carbon dioxide is emitted during savanna burning in the country. It was also observed that the rate of emission in some of the ecological zones varied. This may not be unconnected with the effects of land use changes as reported by Olorunfemi et al. (2019) in the forest zone in the country.

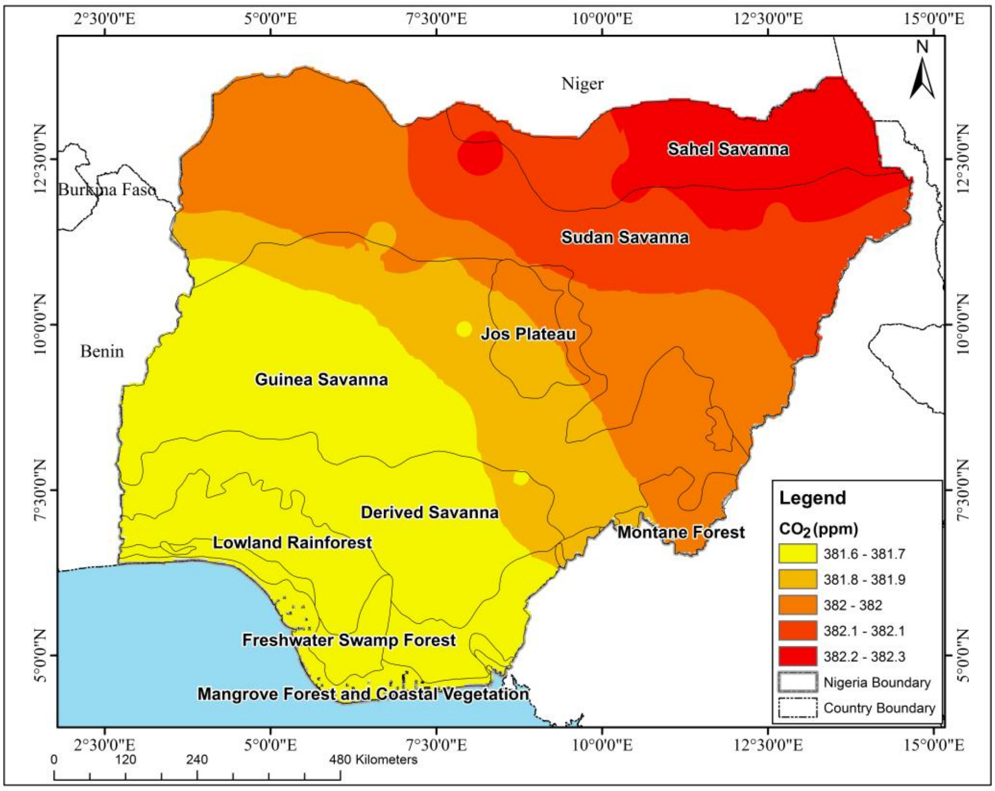

Figure 3: CO_2 variations across the six ecological zones of Nigeria.

Spatial relationship between land surface temperature and carbon dioxide in each ecological zone

Figure 4 shows the relationship between land surface temperature and carbon dioxide which is a positive relationship because the two parameters are increasing with a coefficient of determination of 37.1%. The low value of coefficient of determination indicates that a change in land surface temperature will have little or no effect on the carbon dioxide emissions in the study area. The surface temperature values range between 22.07 °C and 27.24 °C, while the CO_2 values range between 381.61 ppm and 382.27 ppm. This is because the more the carbon dioxide in the atmosphere, the more heat is trapped below the atmosphere which will eventually give rise to more land surface temperature the earth crust being the sink of temperature (Lee 2016). Furthermore, the size of land that is being cleared/opened to direct sunlight will eventually affect the land surface temperature of the area. In other words, the larger the size of the built-up area and bare soil, the higher the land surface temperature of the area (Alabi 2012). The relationship between LST and carbon emissions is further buttressed with the mean trend analysis displayed in Figure 5 which shows that carbon dioxide emissions increased with increased temperature except between year 2011 and 2012 when a slight drop was observed. The LST however, was fluctuating between 2002 and 2007 when an almost constant figure was observed between 2007 and 2009. The LST also fluctuated between 2009 and 2012. The LST- carbon relationship shows that the two parameters increased during the study period.

The increase in carbon dioxide emissions leading to increasing values of land surface temperature could be attributed to the reduction of vegetation being experienced in the region according to Gadiga et al. (2013) who noted that, although the difference in the changes being witnessed between increase and decrease in vegetation cover was not so pronounced, the increase in vegetation cover might be attributed to slight increase in rainfall in the years preceding 1986 and probably as a result of abandonment of farmlands by the migration of people out of the area due to frequent droughts witnessed between 1972 and 1986. Change in land cover/vegetation and emissivity of infrastructural materials greatly influence the surface temperature of a given area. It was also observed that within the urban class, temperature varied due to built up density and emissivity of building materials that were used. Over time, not much variations were found in the Normalized Difference Vegetation Index values, even though the overall vegetation cover is changing to open land or urban land use. This greatly impacts the surface temperature observed in these areas.

Jacob (2015) also reported that the high land surface temperature could be attributed to vegetation loss, properties of infrastructure and surfaces in urban areas and the geometry and arrangement of urban buildings among other factors. Furthermore, forestry, agriculture, and other land use changes account for almost 25% (10-12 gigatones CO_2 equivalent per year; $GtCO_2eq/yr$) of anthropogenic greenhouse gas emissions, due to factors such as deforestation, forest degradation and biomass burning (IPCC 2014). Vetter et al. (2016) also showed that CO_2 emissions and its seasonal cycle strongly depend on climate conditions, for example, a warm winter leads to lower fossil fuel consumption and consequently to lower CO_2 emissions. They stated further the importance of this relationship while evaluating national CO_2 balances as inter-annual emission reductions may not solely result from reduction efforts, but also from climate anomalies. Tubal et al. (2002) pointed out that although concentrations of carbon dioxide in the air are generally high in areas with heavy traffic congestion, the emissions are substantially greater in cold weather because automobiles generally need more fuel to start at cold temperatures and some emission control devices such as oxygen sensors and catalytic converters operate less efficiently when they are cold. Zhang et al. (2018) showed that the carbon dioxide emissions from taxis are huge and advised that policy makers must issue corresponding regulations to reduce carbon dioxide emissions. Gadiga et al. (2013) suggested that more effort is required in establishing and properly managing parks and forest reserves owing to the importance of trees in maintaing balance in the ecological systems. This will help to fight the encroaching desert and mitigate the impacts of climate change. The establishment of trees will also mean reducing the effects of global warming because trees are known to sequester CO_2 in the atmosphere.

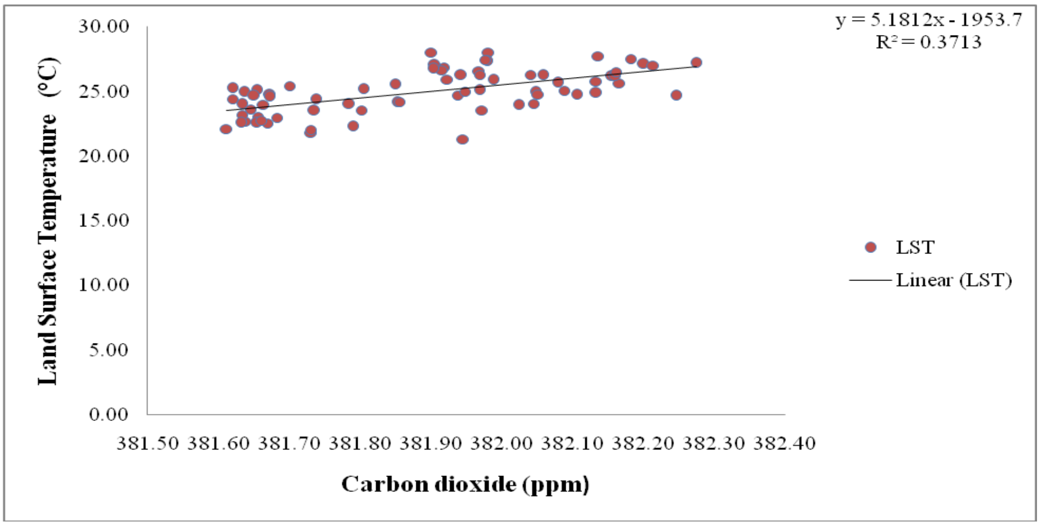

Figure 4: Land surface temperature-carbon relationship.

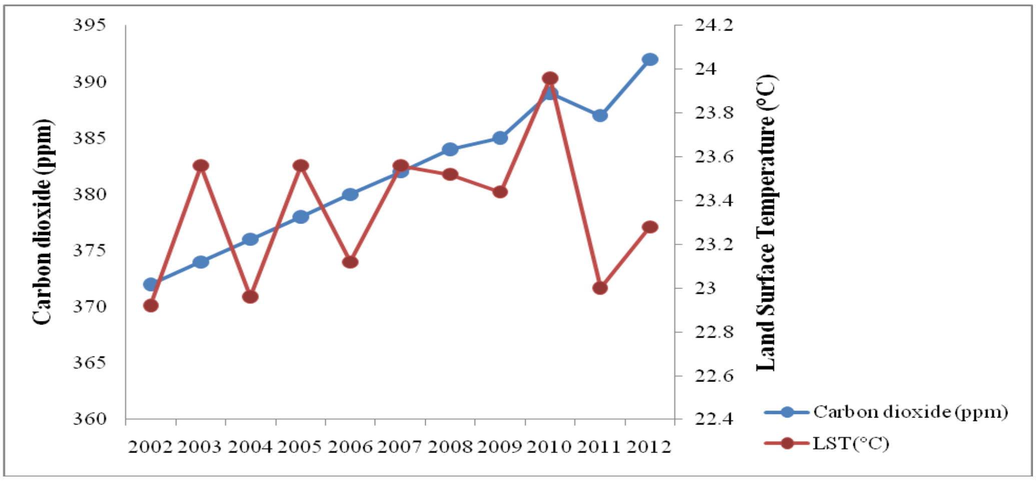

Figure 5: Mean annual trend of carbon dioxide and land surface temperature.

Figure 6 shows the carbon and land surface temperature in the fresh water swamp forest. This is an inverse relationship because as carbon dioxide is increasing, the land surface temperature is reducing with a coefficient of determination of 41.5 %.

Vetter et al. (2016) pointed out that vegetation acts both as a CO_2 source and sink through photosynthesis and ecosystem respiration. It was also discovered that depending on what predominates (either photosynthesis or respiration), the terrestrial ecosystem seasonally can/will turn into a CO_2 sink or source. The main driver behind these seasonal cycles is the rate of incoming solar radiation which not only changes in time, but also varies with space.

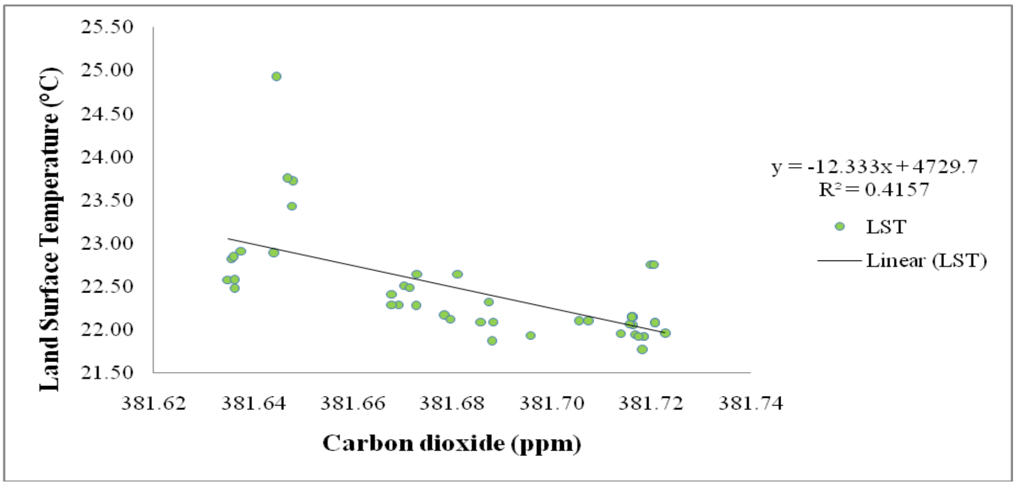

Figure 6: CO_2-LST relationship (freshwater swamp forest).

Figure 7 shows the carbon dioxide and land surface temperature in the Sahel savanna ecological zone. This is a positive relationship because as carbon dioxide is increasing, land surface temperature is also increasing. Monteny et al. (1997) reported that a decrease in soil water availability in the grass root zone during the day brings about an increase in CO_2 accumulation in the atmosphere because it is not absorbed by the grass. The study further stated that there is an increase in CO_2 emission early in the morning due to night respiration of the plant and soil water CO_2 emission. The high land surface temperature values observed here is probably due to the consequence of the nearby Sahara Desert, which has less cloud cover and is therefore more exposed to solar irradiance as explained by Yusuf et al. (2017).

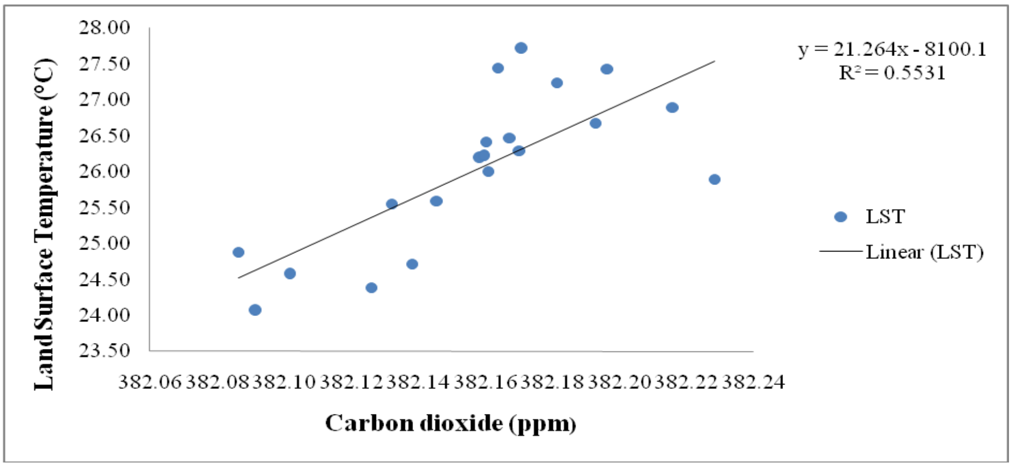

Figure 7: CO_2-LST relationship in the Sahel savanna.

Figure 8 shows the carbon dioxide and land surface temperature in the Sudan savanna ecological zone. The land surface temperature and carbon dioxide are equal which depicts that carbon dioxide has no impact on land surface temperature. The varying levels of carbon dioxide under a fixed temperature indicate the carbon dioxide observations at different locations within the Sudan savanna region. Adepoju et al. (2019) reported that LST increased in savanna, settlements woodlands, riparian vegetation and agricultural lands than in forest and mangrove areas. The small value of R^2 indicates that a change in land surface temperature does not have a significant effect on the levels of carbon dioxide in the Sudan savanna.

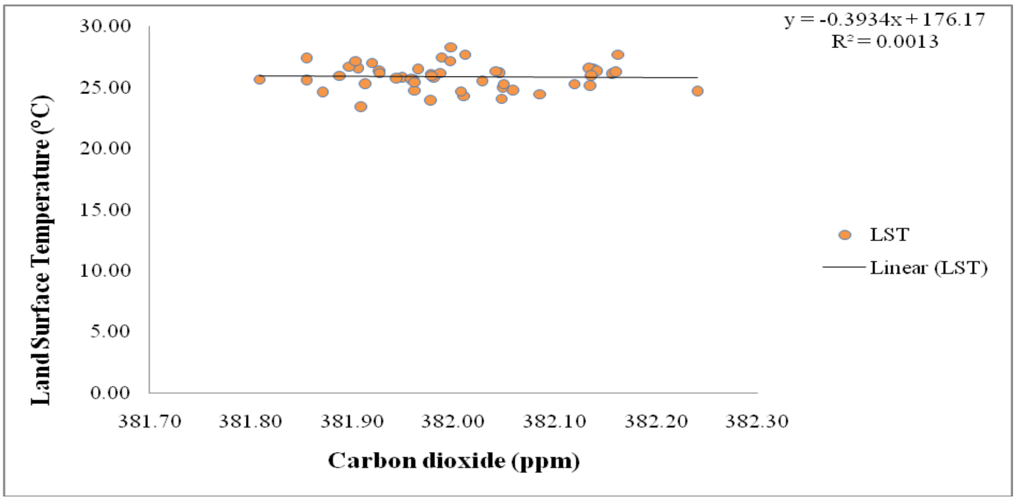

Figure 8: CO_2-LST relationship in the Sudan savanna.

Figure 9 shows the carbon dioxide and land surface temperature in the Guinea savanna ecological zone. It was observed that there is little variation between carbon dioxide and land surface temperature.The increased land surface temperature in this area may be attributed to global warming as posited by Adesina and Odekunle (2011) while evaluating the vulnerability of Nigeria to the impacts of climate change.

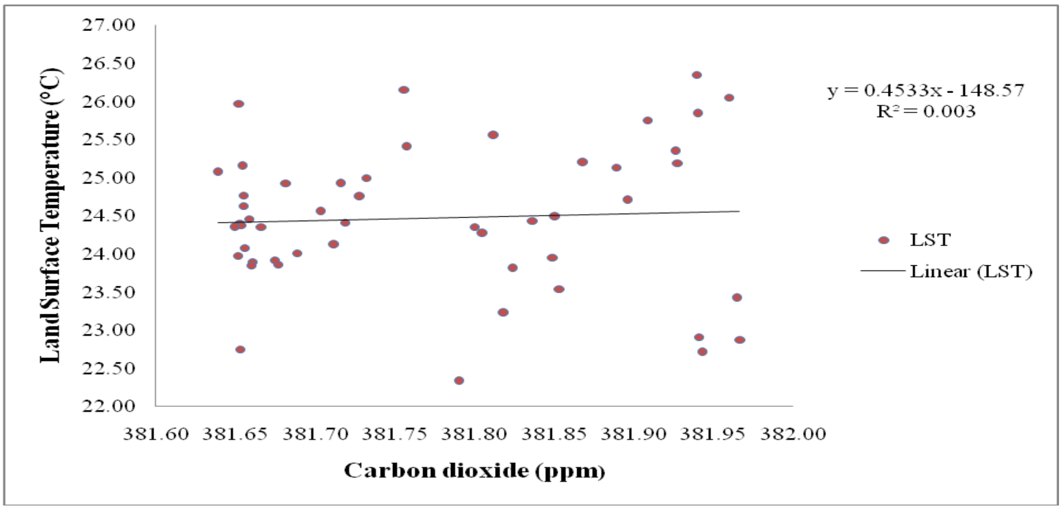

Figure 9: CO_2-LST relationship in the Guinea savanna.

Figure 10 shows the relationship between carbon and land surface temperature in the derived savanna. A positive relationship is observed. The land surface temperature values range between 22 °C to 24.7 °C. This corroborates with an earlier study carried out by Ana and Ogunseye (2015) which shows the positive correlation between CO_2 and temperature.

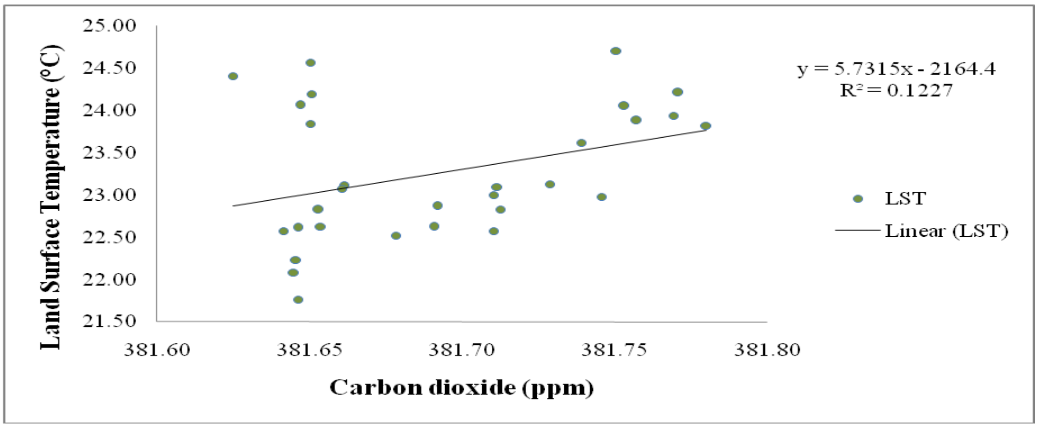

Figure 10: CO_2-LST relationship in the derived savanna.

Figure 11 shows the relationship between carbon dioxide and land surface temperature in the Jos Plateau. It was observed that while there were higher carbon dioxide values, there were also higher land surface temperature values. This is similar to what was obtained in the Guinea savanna. Efe (2016) attributed the high carbon dioxide emissions and temperature observed in the northern cities like Jos to the low vegetal cover expected to absorb the excess CO_2 emissions.

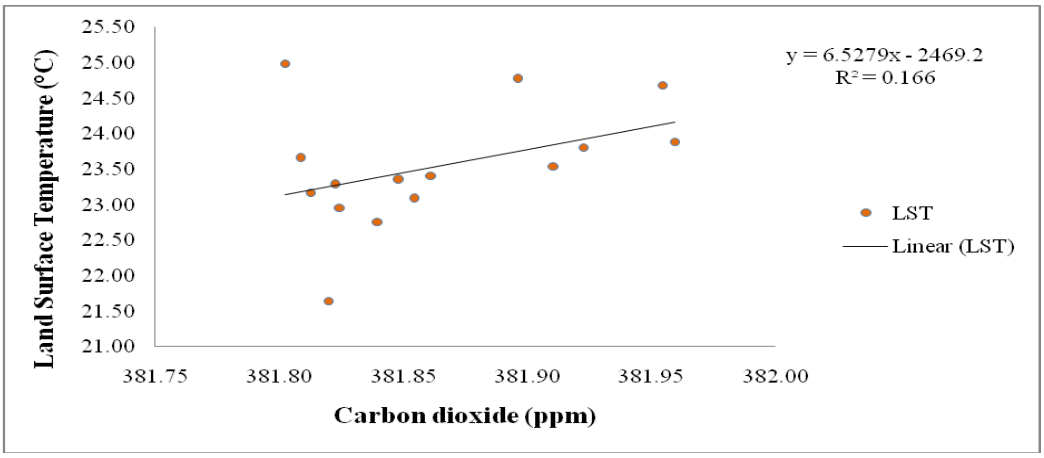

Figure 11: CO_2-LST relationship in the Plateau.

The relationship between carbon dioxide and land surface temperature in the mangrove is presented in Figure 12.The pattern here is similar to what was obtained in the fresh water swamp forest. Hamilton (2013) and Hamilton and Casey (2016) reported that deforestation contributes to anthropogenic greenhouse gas emissions in the mangrove forests because the mangrove forests can hold more organic carbon per unit area when compared to other terrestrial forested ecosystems that are being deforested in the tropics.

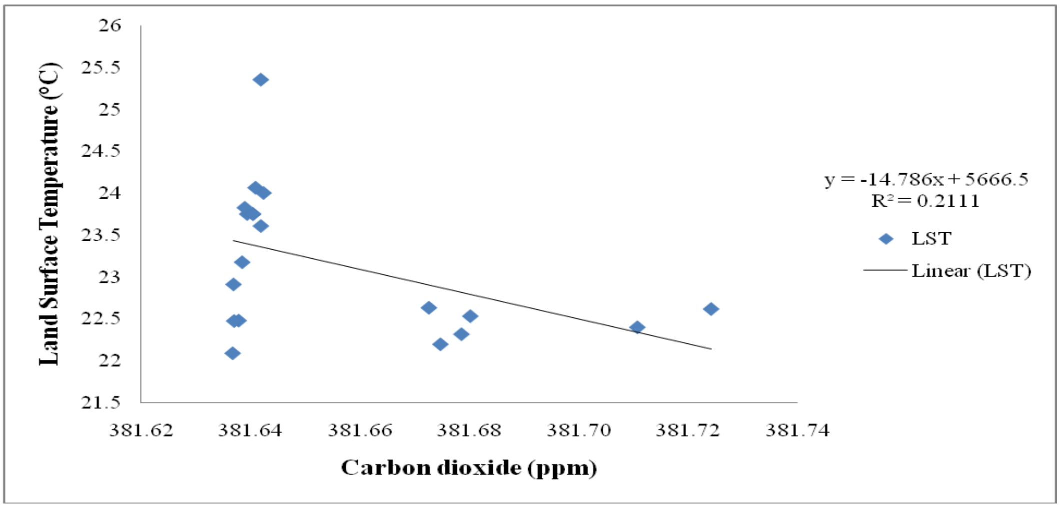

Figure 12: CO_2-LST relationship in the mangrove.

The relationship between carbon and land surface temperature in the lowland rainforest is presented in Figure 13. Surface temperature ranges from 22 °C to 24 °C, while the CO_2 values range between 381.63 ppm and 381.80 ppm. The variation observed here is not much. The temperature and CO_2 values are in tandem with earlier studies carried out by various authors for different locations within the region. Pan et al. (2011) and Houghton et al. (2015) reported the role of tropical forests in the global carbon cycle as carbon sink, while MacCarthy et al. (2018) noted that low emission of CO_2 was observed from the forest while assessing greenhouse gas emissions from different land use systems in southern Ghana.

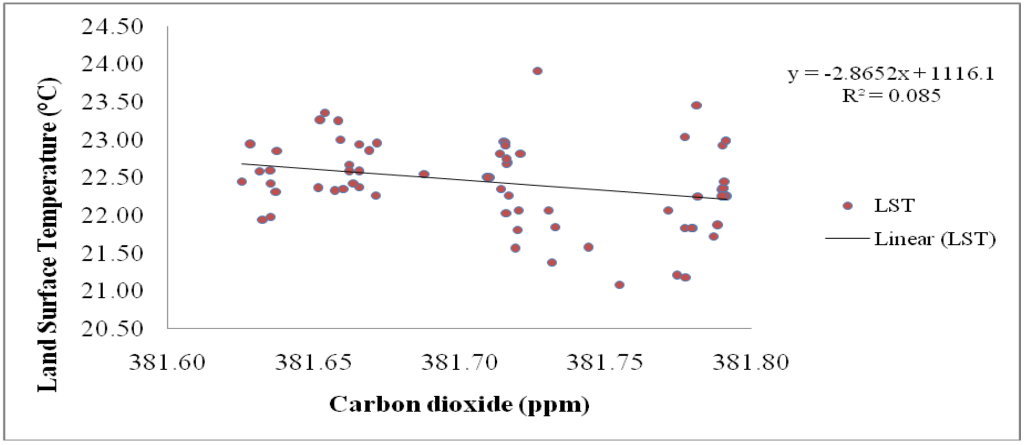

Figure 13: CO_2-LST relationship in the lowland rainforest.

Conclusion

The study has shown that the emissions of CO_2 increased from the coast to the hinterland as well as that of LST during the study period. The LST and rate of CO_2 emissions were also observed to vary within the same ecological zone. The study also confirmed that an increase in CO_2 emission brought about an increase in surface temperature with the exception of the freshwater swamp forest and the mangrove swamp forest where an inverse relationship was observed. Areas with less vegetal cover were observed to have higher LST and higher rates of CO_2 emissions. The increase in the rates of carbon dioxide emissions in such areas may be attributed to the high rates of removal of vegetation for urbanization and other economic activities. The increase in CO_2 and LST will lead to adverse climate changes which portends great danger for the country because of its adverse impacts on different sectors of the economy. There is the need to discourage felling of trees in the various ecological zones in the country to enhance carbon sequestration and thus reduce the adverse impacts of climate changes which are already evident in the country.

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